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Emission Factors for Iron Foundries: Criteria and Toxic Pollutants

Pechan (E.H.) and Associates, Inc., Durham, NC

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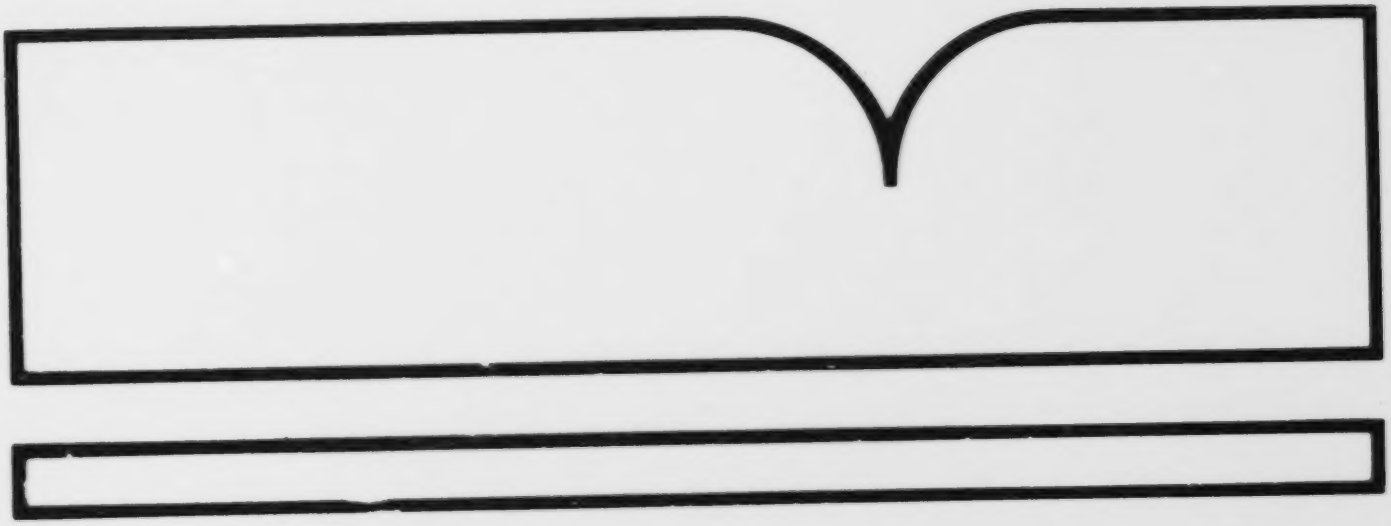

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EMISSION FACTORS FOR IRON FOUNDRIES - CRITERIA AND TOXIC POLLUTANTS

by

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Foundries	Stationary Sources	13I
Emission	Emission Factors	14G
Toxicity	Criteria Pollutants	06T
	Toxic Pollutants	

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FOREWORD

During the past several years, attention has mostly focused on emissions of criteria pollutants. These pollutants include particulate matter, sulfur dioxide, carbon dioxide, nitrogen oxides, volatile organic compounds, and lead. More recently, attention has focused on air toxic pollutants. These pollutants include many different compounds. This report summarizes the information available for both types of pollutants for iron foundry sources. It serves as a guide for estimating the emissions when emission measurements are not available.

ABSTRACT

This report provides a comprehensive list of criteria and toxic pollutant emission factors for sources commonly found in iron foundries. Emission factors are identified for process sources and process fugitive emissions. The emission factors represent uncontrolled emissions. These factors may be used to estimate emissions when site-specific information is not available.

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SECTION 1

INTRODUCTION

Iron foundries have been identified in certain areas of the country to be potentially significant sources of air pollution. The Control Technology Center of the U.S. Environmental Protection Agency, in response to a request for air toxic emission factors by the Hamilton County Air Pollution Control Bureau of Chattanooga, Tennessee, commissioned this report. The report is an attempt to compile all current emission factor information that may be used by state and local agencies in estimating emissions from iron foundries. This report is a follow-on to a previous report on emission factors for iron and steel manufacturing facilities.

The objective of this study is to provide a comprehensive set of emission factors for sources of both criteria and toxic air pollutants in 'gray' and ductile iron foundries. Emission factors are identified for process sources, process fugitive and open source fugitive emissions. The emission factors are not specific to any one facility.

During the past several years, attention has mostly focused on emissions of criteria pollutants. These pollutants include particulate matter, sulfur dioxide, carbon dioxide, nitrogen oxide, volatile organic compounds, and lead. More recently, attention has focused on air toxic pollutants. These pollutants include many different compounds. This report summarizes the information available for both types of pollutants. It serves as a guide for estimating the emissions when emission measurements are not available.

This study was accomplished by conducting a literature search of the library of the U.S. EPA and the American Foundrymen's Society. Articles were reviewed for any information that could be used to develop emission factors for any of the processes associated with iron foundries. The emission factors are presented in terms of an average value or range of values together with a rating of quality or reliability.

SECTION 2

POLLUTANT EMITTING PROCESSES

Iron foundries produce iron castings from scrap iron, pig iron, and foundry returns by melting, alloying, and molding. The major operations include 1) raw material handling and preparation, 2) metal melting, 3) mold and core production, and 4) casting and finishing.[1]

RAW MATERIAL HANDLING AND PREPARATION

Handling operations include receiving, unloading, storing, and conveying of all raw materials for both furnace charging and mold and core preparation. The major groups of raw materials required for furnace charging are metallics, fluxes, and fuels. Metallic raw materials include pig iron, iron and steel scrap, foundry returns, and metal turnings. Fluxes include carbonates (limestone, dolomite), fluoride (fluorspar), and carbide compounds (calcium carbide). Fuels include coal, oil, natural gas, and coke. Coal, oil, and natural gas are used to fire reverberatory furnaces. Coke, a derivative of coal, is used as a fuel in cupola furnaces. Although not a true fuel, carbon electrodes are required for heat production in electric arc furnaces.

As shown in Figures 1 and 2, the raw materials, metallics, and fluxes are added to the melting furnaces directly. For electric induction furnaces, however, the scrap metal added to the furnace charge must first be pretreated to remove any grease and/or oil, which can cause explosions. Scrap metals may be degreased with solvents, by centrifugation, or by preheating to combust the organics.

In addition to the raw materials used to produce the molten metal, a variety of materials are needed to prepare the sand cores and molds used to form the iron castings. Virgin sand, recycled sand and chemical additives are combined in a sand handling system typically composed of receiving areas, conveyors, storage silos and bins, mixers (sand mullers), core and mold making machines, shakeout grates, sand cleaners, and sand screening.

Raw materials are transported in ships, railroad cars, trucks, and containers, and then are transferred by truck loaders, and conveyors to both open piles and enclosed storage areas. When needed, the raw materials are transferred from storage to process areas by similar means.

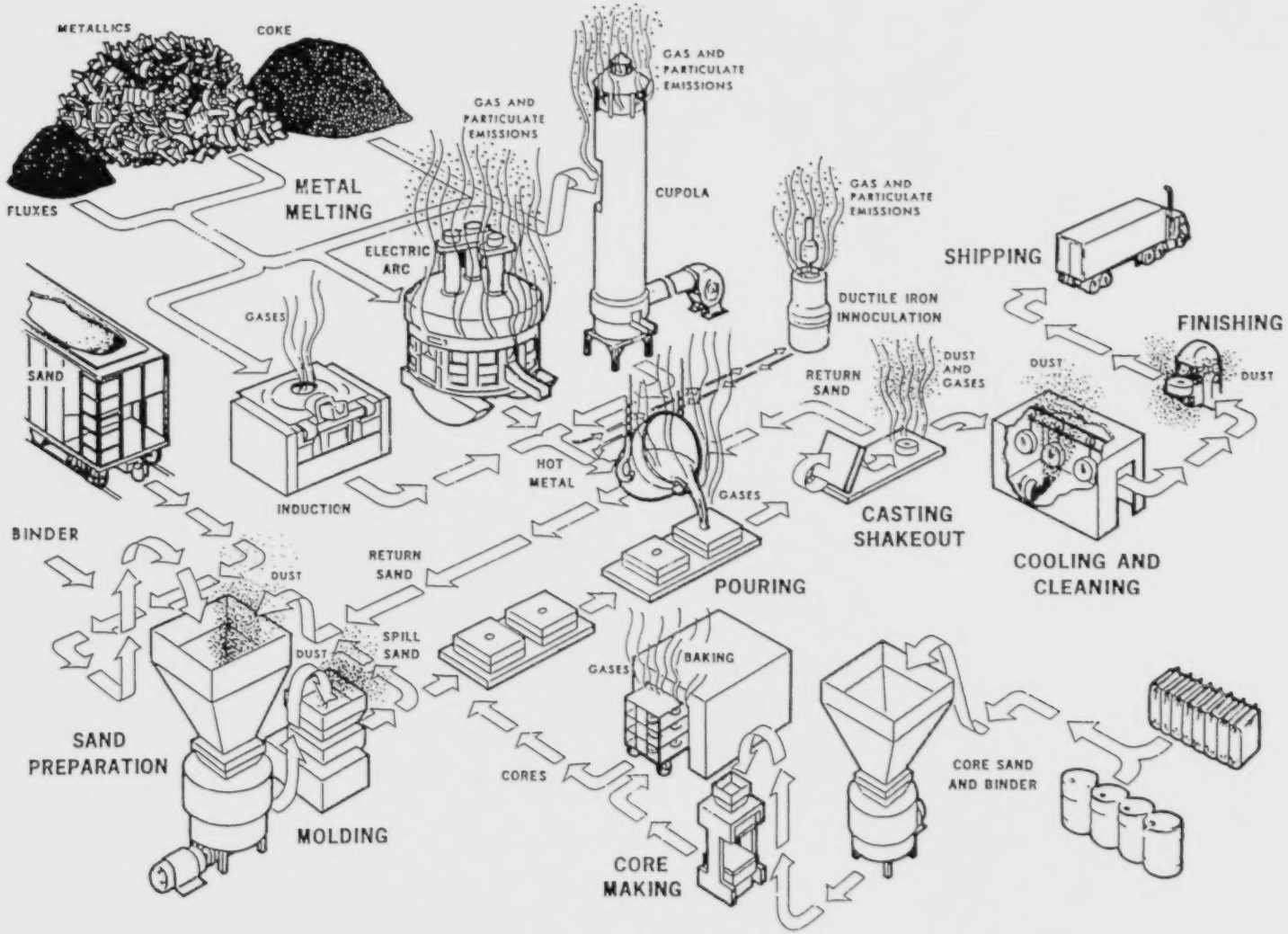

Figure 1. Emission points in a typical iron foundry.[1]

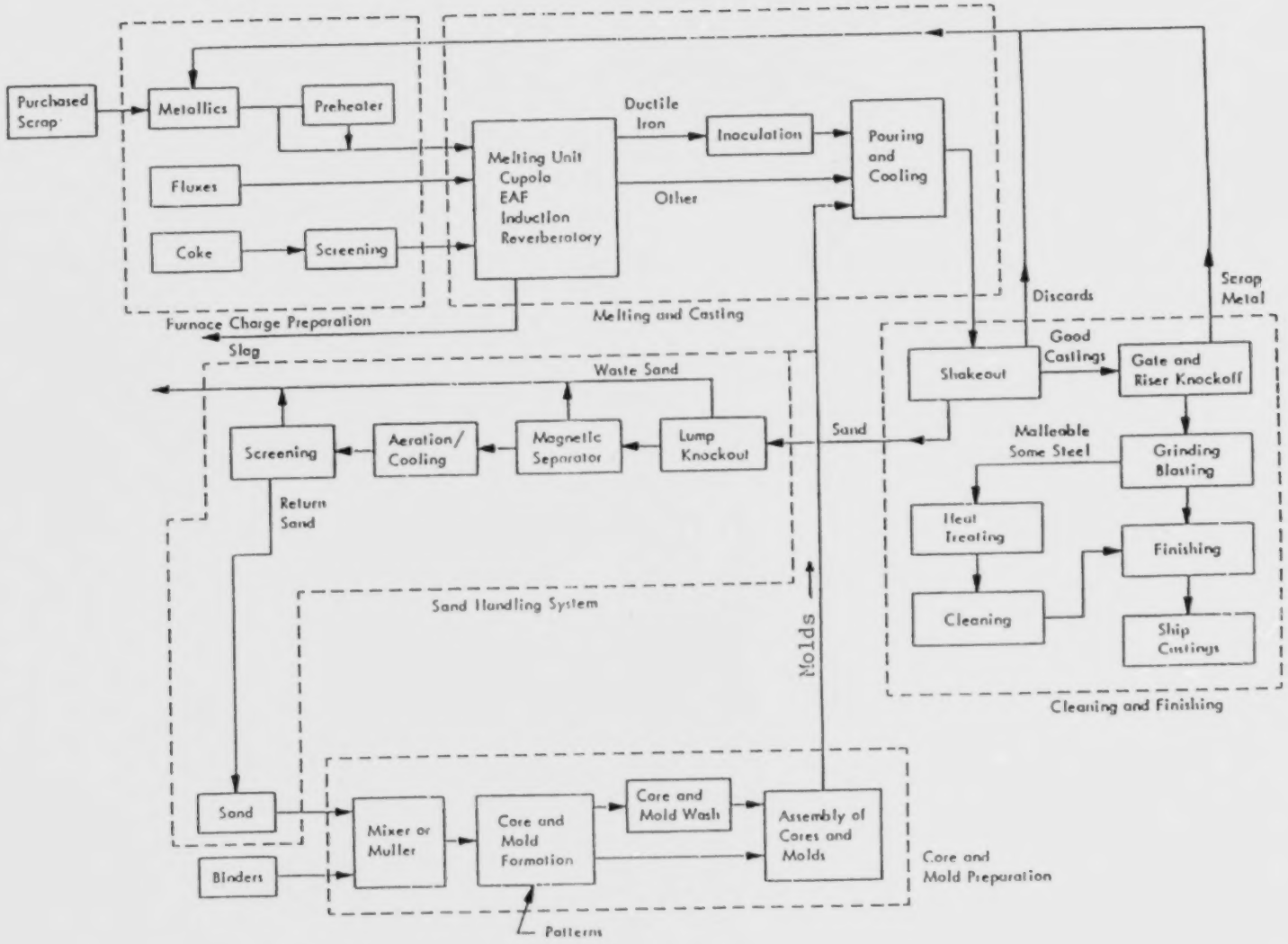

Figure 2. Typical iron foundry diagram.[1]

METAL MELTING

The furnace charge includes metallics, fluxes, and fuels. The composition of the charge depends upon the specific metal characteristics required. Table 1 lists the different chemical compositions of typical irons produced. The three most common furnaces used in the gray iron foundry industry are cupolas, electric arc, and electric induction furnaces.

TABLE 1. CHEMICAL COMPOSITION OF FERROUS CASTINGS BY PERCENTAGES

Element	Gray iron	Malleable iron (as white iron)	Ductile iron	Steel
Carbon	2.5 - 4.0	1.8 - 3.6	3.0 - 4.0	<2.0[a]
Silicon	1.0 - 3.0	0.5 - 1.9	1.4 - 2.0	0.2 - 0.8
Magnesium			0.01 - 1.0	
Manganese	0.40 - 1.0	0.25 - 0.80	0.5 - 0.8	0.5 - 1.0
Sulfur	0.05 - 0.25	0.06 - 0.20	<0.12	<0.06
Phosphorus	0.05 - 1.0	0.06 - 0.18	<0.15	<0.05

[a]Steels are classified by carbon content: low carbon; <0.20 percent, medium carbon; 0.20 - 0.5 percent, high carbon; >0.50 percent.

Cupolas

The cupola, which is the major type of furnace used in the foundry industry today, is typically a vertical cylindrical steel shell with either a refractory lined or water cooled inner wall. Refractory linings usually consist of silica brick, or dolomite or magnesium brick. Water cooled linings, which involve circulating water around the outer steel shell, are used to protect the furnace wall from interior temperatures. The cupola is charged at the top with alternate layers of coke, metallics, and fluxes.

The cupola is the only furnace type to use coke as a fuel; combustion air used to burn the coke is introduced through tuyeres located at the base of the cupola. Cupolas use either cold blast air, air introduced at ambient temperature, or hot blast air which may be heated with a regenerative system which utilizes heat from the cupola exhaust gases to preheat the combustion air.

Iron is melted by the burning coke and flows down the cupola. As the melt proceeds, new charges are added at the top. The flux removes non-metallic impurities in the iron to form slag. Both the molten iron and the slag are removed through tap holes at the bottom of the cupola. Periodically, the heat period is completed, and the bottom of the cupola is opened to remove the remaining unburned material.

Cupola capacities range from 1 to 27 megagrams per hour (1 to 30 tons per hour), with a few larger units approaching 90 megagrams per hour (100 tons per hour). Larger furnaces operate continuously and are inspected and cleaned at the end of each week or melting cycle.

Electric Arc Furnaces

Electric arc furnaces (EAF) are large, welded steel cylindrical vessels equipped with a removable roof through which three retractable carbon electrodes are inserted. The electrodes are lowered through the roof of the furnace and are energized by three phase alternating current, creating arcs that melt the metallic charge with their heat. Additional heat is produced by the resistance of the metal between the arc paths.

The most common method of charging an electric arc furnace is by removing the roof and introducing the raw materials directly. Alternative methods include introducing the charge through a chute cut in the roof or through a side charging door in the furnace shell. Once the melting cycle is complete, the carbon electrodes are raised, and the roof is removed. The vessel is tilted, and the molten iron is poured into a ladle. Electric arc furnace capacities range from 0.23 to 59 megagrams (0.25 to 65 tons). Nine to 11 pounds of electrode are consumed per ton of metal melted.

Electric Induction Furnaces

Electric induction furnaces are either cylindrical or cup shaped refractory lined vessels that are surrounded by electrical coils which, when energized with high frequency alternating current, produce a fluctuating electromagnetic field to heat the metal charge. For safety reasons, the scrap metal added to the furnace charge is cleaned and heated before being introduced into

a furnace. Any oil or moisture on the scrap could cause an explosion in the furnace. Induction furnaces are kept closed except when charging, skimming, and tapping. The molten metal is tapped by tilting and pouring through a hole in the side of the vessels. Induction furnaces also may be used for metal refining in conjunction with melting in other furnaces and for holding and superheating the molten metal before pouring (casting).

The basic melting process operations are 1) furnace charging, in which metal, scrap, alloys, carbon, and flux are added to the furnace; 2) melting during which the furnace remains closed; 3) backcharging, which involves the addition of more metal and alloys, as needed; 4) refining and treating, during which the chemical composition is adjusted to meet product specifications; 5) slag removing; and 6) tapping molten metal into a ladle or directly into molds.

Inoculation

Inoculation is the process whereby magnesium and other elements are added to molten gray iron, to produce ductile iron.

Ductile iron is formed as a steel matrix containing spheroidal particles (or nodules) of graphite. Ordinary cast iron, that is, gray cast iron, contains flakes of graphite. Each flake acts as a crack, with the result that cast iron is well known for its brittleness. Ductile irons are very silvery in appearance and are noted for their tensile strength.

Inoculation of the molten iron has been accomplished in many diverse ways, however the two most common methods are plunging and pour over. In plunging, magnesium or a magnesium alloy is loaded into a graphite "bell" which is plunged into the ladle of molten iron. A turbulent reaction takes place as the magnesium boils under the heat of the molten iron. As much as 65 percent of the magnesium may be lost in the inoculation process, as the magnesium vapor issuing from the iron ignites in air, creating large amounts of smoke.

In the pour over method, the magnesium alloy is placed in the bottom of a vessel and molten iron is poured over it. Although this method produces more emissions and is less efficient than plunging, it requires no capital equipment other than air pollution control.

MOLD AND CORE PRODUCTION

Molds are forms used to shape the exterior of castings. Cores are molded sand shapes used to make the internal voids in castings. Cores are made by mixing sand with organic binders or organic polymers, molding the sand into a core, and baking the

core in an oven. Molds are prepared of a mixture of wet sand, clay and organic additives to make the mold shapes, which are usually dried with hot air. Cold setting binders are being used more frequently in both core and mold production. The green sand mold, the most common type, uses moist sand mixed with 4 to 6 percent clay (bentonite) for bonding. The mixture has a water content of 4 to 5 percent. Added to the mixture, to prevent casting defects from sand expansion when the hot metal is poured, is about 5 percent organic material, such as sea coal (a pulverized high volatility bituminous coal), wood flour, oat hulls, pitch or similar organic matter.

Common types of gray iron cores include the following:

- Oil core, with typical sand binder of 1.0 percent core oil, 1.0 percent cereal, and 0 to 1 percent pitch or resin. Cured by oven baking at 205 to 314°C (400 to 600°F), for 1 to 2 hours.

- Shell core, with sand binder typically 3 to 5 percent phenolic and/or urea formaldehyde, with hexamine activator. Cured as a thin layer on a heated metal pattern at 205 to 315°C (400 to 600°F), for 1 to 3 minutes.

- Hot box core, with sand binder typically 3 to 5 percent furan resin, with phosphoric acid activator. Cured as a solid core in a heated metal pattern at 205 to 315°C (400 to 600°F), for 0.5 to 1.5 minutes.

- Cold set core, with typical sand binder percents of 3 to 5 furan resin, with phosphoric acid activator; or 1 to 2 core oil, with phosphoric acid activator. Hardens in the core box. Cured for 0.5 to 3 hours.

- Cold box core, with sand binder typically 1 to 3 percent of each of two resins, activated by a nitrogen diluted gas. Hardens when the green core is gassed in the box with polyisocyanate in air. Cured for 10 to 30 seconds.

Used sand from castings shakeout is recycled to the sand preparation area and cleaned to remove any clay or carbonaceous buildup. The sand is then screened and reused to make new molds. Because of process losses and discard of a certain amount of sand because of contamination, makeup sand is added.

CASTING AND FINISHING

After the melting process, molten metal is tapped from the furnace. Molten iron produced in cupolas is tapped from the bottom of the furnace into a trough, then into a ladle. Iron produced in electric arc and induction furnaces is poured

directly into a ladle by tilting the furnace. At this point, the molten iron may be treated with magnesium to produce ductile iron. The magnesium reacts with the molten iron to nodularize the carbon in the molten metal, producing a less brittle iron. At times, the molten metal may be inoculated with graphite to adjust carbon content. The treated molten iron is then ladled into molds and transported to a cooling area, where it solidifies in the mold and is allowed to cool further before separation (shakeout) from the mold and core sand.

In larger, more mechanized foundries, the molds are conveyed automatically through a cooling tunnel. In simpler foundries, molds are placed on an open floor space, and the molten iron is poured into the molds and allowed to cool partially. Then the molds are placed on a vibrating grid to shake the mold and core sand loose from the casting. In the simpler foundries, molds, core sand and castings are separated manually, and the sand from the mold and core is then returned to the sand handling area.

When castings have cooled, any unwanted appendages, such as spurs, gates, and risers, are removed. These appendages are removed with oxygen torches, abrasive band saws, or friction cutting tools. Hand hammers may be used, in less mechanized foundries to knock the appendages off. The castings are then subjected to abrasive blast cleaning and/or tumbling to remove any remaining mold sand or scale.

Another step in the metal melting process involves removing the slag in the furnace through a tapping hole or door. Since the slag is lighter than molten iron, it remains atop the molten iron and can be raked or poured out of cupola furnaces through the slag hole located above the level of the molten iron. Electric arc and induction furnaces are tilted backwards, and their slag is removed through a slag door.

Greensand Shakeout

The most elementary method of removing castings from a mold is to dump the mold, and hook, or pull out, the casting from the sand. When significant production is required, the molds are automatically inverted and dumped onto a vibrating grating which shakes out the sand and separates the casting. The sand falls through the grating and onto a conveyor belt which carries it to the conditioning and reprocessing system. In some cases the shakeout can be a long vibrating grate (30 meters), such as for gasoline engine blocks and heads, where much internal core sand must be removed. There are many variations of shakeout systems, including heavy screen drums that rotate batches of castings and long cylindrical perforated cylinders that tumble the parts and process parts continuously.

The shakeout has the potential to generate the most fumes of the many foundry operations (except melting). By the time the mold assembly reaches the shakeout, the bulk of the thermal decomposition of the mold/core materials has occurred. The products of thermal decomposition will tend to be lower molecular weight materials and will vaporize and diffuse away from the hot metal-sand interface into the cooler sand. Some of the organic emissions will condense and adsorb on the cooler sand of the mold. Most compounds with boiling points below 100°C will be either emitted during the cooling process or undergo chemical reactions and released as other pollutants. During shakeout, the cooler sand comes into contact with the hot sand surrounding the metal, and the metal itself. This causes a flash boiling, thereby producing an emission of the pyrolysis products. In addition, there will be a lesser amount of decomposition (than occurs during pouring) of the organic constituents.

SECTION 3

CRITERIA POLLUTANT EMISSION FACTORS

U.S. EPA publication AP-42, Compilation of Air Pollutant Emission Factors[2] provides the best guidance on emission factors for criteria pollutants. The AP-42 section on iron foundries is provided in Appendix A.

To help users understand the reliability and accuracy of AP-42 emission factors, each table in an AP-42 section (and sometimes individual factors within a table) is given a rating (A through E, with A being the best) which reflects the quality and the amount of data on which the emission factors are based.

In general, factors based on many observations or on more widely accepted test procedures are assigned higher ratings. For instance, an emission factor based on ten or more source tests on different plants would likely get an A rating, if all tests were conducted using a single valid reference measurement method or equivalent technique. Conversely, a factor based on a single observation of questionable quality, or one extrapolated from another factor for a similar process, would probably be labeled D or E. Several subjective schemes have been used in the past to assign these ratings, depending upon data availability, source characteristics, etc.

Because these ratings are subjective and take no account of the inherent scatter among the data used to calculate factors, they should be used only as approximations, to infer error bounds or confidence intervals about each emission factor. At most, a rating should be considered an indicator of the accuracy and precision of a given factor used to estimate emissions from a large number of sources. This indicator will largely reflect the professional judgement of the authors and reviewers of AP-42 Sections concerning the reliability of any estimates derived with these factors.

The rating scheme used in this report is summarized below.

A Developed from A-rated test data taken from many randomly chosen facilities in the industry population.

B Developed only A-rated test data from a reasonable number of facilities.

C Developed only from A- and B-rated test from a reasonable number of facilities.

D Developed from only A- and B-rated test data from a small number of facilities.

E Developed from C- and D-rated test data and there may be reason to suspect that the facilities tested do not represent a random sample of the industry.

Most of the information available from AP-42 regarding criteria pollutant emissions from iron foundries pertains to particulate matter.

Appendices B, C, and D are the sources of the emission factors presented in Table 2 and portions of Table 3, as indicated. Appendix B, Toxic Air Pollutant Emission Factors for Iron Foundries, gives emission factors for various foundry furnaces under controlled and uncontrolled conditions. This report uses the uncontrolled emissions factors, which have been expressed as units mg/Mg metal melted (tapped from furnace).

Appendix C, Criteria Air Pollutant Emission Factor for Gray Iron Foundries, presents uncontrolled emissions of criteria pollutants from various processes in iron foundries. The criteria pollutants are total particulates, particulate matter less than ten microns (PM_{10}), oxides of sulfur (SO_x), oxides of nitrogen (NO_x), volatile organic compounds (VOC), carbon monoxide (CO), and lead. Where applicable, emission factors are expressed as mg/Mg metal melted, and presented in Table 2.

Appendix D, Threshold Limit Values and Biological Exposure Indices for 1988-1989, presents substances common to foundry processes and their effects on humans in the work environment. This information serves to qualify the pollutant emission factors in this report into human exposure terms, and explains their effects on the human body.

Additional emission factors for criteria pollutants (especially non-particulate pollutants) have been developed as part of the National Acid Precipitation Assessment Program (NAPAP). The major objective of NAPAP was to develop volatile organic compound (VOC) emission factors for Source Classification Codes (SCC) that had no emission factors in either AP-42 (4th Edition) or AP-42, Supplement A. Also included in that work was the development of nitrogen oxides (NO_x) and sulfur dioxide (SO_2) emission factor estimates for SCC's which were included in reports submitted by States that previously lacked these factors.

The new emission factors that resulted from the NAPAP effort are typically not of the same quality as those found in AP-42. The NAPAP factors represent best estimates and were generated from estimates taken from the literature, from averaging data submitted by 13 State air quality offices, and through technology transfer of emission factors for SCC's from similar industries. The emission factors generated in the NAPAP work have been rated E due to lack of rigorous quality assurance.

The emission factors developed for the NAPAP emission inventory normally represent uncontrolled emissions. For PM_{10} emission factors, AP-42 should be consulted since the particulate emission factors developed as part of the NAPAP effort were for total suspended particulates (TSP), not PM_{10}.

Criteria air pollutant emission factors for foundry processes are presented in Table 2. Those emission factors derived from AP-42[2] represent a range of emissions, samples and foundries under which testing was conducted. Those emission factors derived from NAPAP were developed from States files, published reports from both industrial and government sources, AP-42, engineering estimates, and personal communication with various industry representatives. In the instances where NAPAP used AP-42 data, the AP-42 data range was averaged to present a single value.

TABLE 2. CRITERIA EMISSIONS, mg/Mg METAL MELTED

	Cupola	Electric Arc Furnace	Inoculation[a]	Pouring	Greensand Shakeout	Notes/References
PM_{10}	6.2×10^6	5.8×10^6		1.03×10^6	1.12×10^6	AP-42[2]
	6.2×10^6	5.7×10^6	1.6×10^6	2.5×10^6	1.12×10^6	NAPAP[3]
VOC	9×10^4	9×10^4	2.5×10^3	7×10^4	6×10^5	NAPAP[3]
		3×10^4 - 1.5×10^5	---	---	---	AP-42[2]
NO_x	5×10^4	9.0×10^4	---	5×10^3	Neg	NAPAP[3]
		2×10^4 - 3×10^5	---	---	---	AP-42[2]
CO	7.25×10^7	9.5×10^6	---	---	---	NAPAP[3]
	7.25×10^7	5×10^4 - 1.9×10^5	---	---	---	AP-42[2]
SO_x	1.8×10^3	Neg	---	---	---	AP-42[2]
		1.25×10^5	---	1.0×10^4	Neg	NAPAP[3]

---

[a]Units are expressed as mg/Mg metal inoculated.

Neg = negligible

Dash = no data

SECTION 4

TOXIC POLLUTANT EMISSION FACTORS

Iron foundries produce toxic pollutants from five major processes. These processes include metal melting, mold and core production, inoculation, pouring, and greensand shakeout. Baldwin[4,5] measured concentrations of toxic air emissions for different foundry processes; from these concentration measurements, sampling data, and site parameters, emission factors have been calculated which give a breakdown of the emissions from iron foundries.

The toxicity of a material and the extent to which that material is present merits a corresponding "level of concern"; the primary level of concern is noted for different foundry process. Emissions may be discharged both directly and indirectly into the surrounding air. Toxic organic emissions are presented in Table 3 for each of these processes. Toxic inorganic emissions are presented in Table 4. Since magnesium (abbreviated Mg) is a major toxic pollutant, and emission factors are reported as mg/Mg (milligrams per megagram iron produced), the element magnesium will be spelled out to avoid confusion.

METAL MELTING

Cupolas

Toxic emissions from cupolas include both organic and inorganic materials, which may be emitted directly or indirectly. Cupolas are the primary process of melting in foundries and also produce the most toxic emissions. It is estimated that 68.8 percent of all the health risk from foundries is from foundries with cupolas.[6] The cupola organic emissions factors which are of primary concern are:

- o halogenated hydrocarbons 1.92 mg/Mg
- o aromatic hydrocarbons 1.70 mg/Mg
- o halogenated aromatics 1.70 mg/Mg
- o silicones 0.43 mg/Mg
- o heterocyclic N compounds 0.16 mg/Mg
- o amines 0.14 mg/Mg

TABLE 3. ORGANIC EMISSIONS, mg/Mg IRON PRODUCED

	Electric Arc Furnaces[a]	Cupola[a]	Inoculation[a]	Pouring[a]	Green Sand Shakeout[b]
Aliphatic Hydrocarbons	4.94	1.92	0.08	0.78	0.39
Halogenated Hydrocarbons	4.94	1.92	0.08	0.78	
Aromatic Hydrocarbons	3.41	1.70	0.19	0.56	1.34
Fused Aromatics (>216 MW)					1.34
Halogenated Aromatics	3.41	1.70	0.05	0.56	0.13
Heterocyclic N Compounds	0.12	0.16	0.01	0.14	0.56
Heterocyclic S Compounds	0.12	0.16	0.01	0.14	0.05
Alcohols	0.40	0.14	0.01	0.26	0.31
Phenols	0.12	0.14	0.06	0.05	0.31
Ketones	0.84	1.51	0.01	0.42	0.05
Amines	0.40	0.14	0.01	0.31	0.31
Silicones	0.37	0.43	0.18	0.07	
Heterocyclic O Compounds	1.63	1.01	0.00	0.47	0.05
Nitroaromatics	0.00	0.11	0.05	0.03	0.01
Ethers	0.02	1.10	0.01	0.2	0.05
Aldehydes	0.00	0.11	0.01	0.03	0.05
Phosphates	0.82	0.16	0.00	0.06	
Nitriles	0.00	0.11	0.01	0.03	0.01
Alkyl S Compounds	0.12	0.14	0.01	0.08	0.03
Sulfonic Acids	0.12	0.14	0.01	0.06	0.03
Sulfoxides	0.12	0.14	0.01	0.05	
Amides	0.12	0.14	0.01	0.09	0.23
Carboxylic Acids	0.4	0.14	0.01	0.26	0.25
Esters	0.12	0.89	0.02	0.22	0.15
Haloaliphatics					0.12

[a] Baldwin[5]

[b] Baldwin[4]

NOTE: Emission factors for organic emissions from electric induction furnaces are not presently available.

TABLE 4. INORGANIC EMISSIONS, mg/Mg IRON PRODUCED*

Element	Cupola	Electric Arc Furnace	Inoculation	Pouring
Ag			8.7	1.0
Al			55	>66
As	26.1		7.3 - 26.8	0.1
B		81	56	57
Ba			55	65
Be			0.02	0.04
Bi			3.6	0.1
Ca			56	>66
Cd		1,654[a]	1.5	0.8
Ce			>66	3.1
Co			0.1	0.35
Cr		97	4.0	>66
Cs			0.7	
Cu	850[b]		11.7	14.7
Eu				0.04
F		6,614[a]	>66	
Fe			55.8	>66
Ga			1.2	0.7
Ge			0.06	
Hg		36	22	11
K			56	>66
La			9.4	2.6
Li				3.4
Magnesium			56	>66
Mn	125,000[b]	65	35	>66
Mo			5.1	6.7
Na			56	>66
Nb				0.5
Nd				0.1
Ni			0.31	25
P			15	>66
Pb	5×10^4 - 5.5×10^{5}[c] 2.6×10^{5}[d]	323	56	11
Pr				0.1
Rb			9.4	0.2
S			56	>66
Sb			159	0.8
Sc			0.04	0.13
Se			5.8	0.1
Si			56	>66
Sm				0.2
Sn			18	1.0
Sr			72.5	4.0

TABLE 4. (Continued)

Element	Cupola	Electric Arc Furnace	Inoculation	Pouring
Te			1.5	0.2
Th				1.1
Ti			56	>66
U				0.4
V			56	>66
W				0.1
Y			0.7	0.8
Zn			56	>66
Zr			29	4.0

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*All emission factors are calculated from Baldwin 1982,[5] except as noted:

[a]N.D. Johnson[7]

[b]Toxic Air Pollution Emission Factors

[c]AP-42[2] (source of data in AP-42 is Reference 8).

[d]Criteria Air Pollution Emission Factors for the 1985 NAPAP Emission Inventory.

A blank value indicates only that no data is available in the literature and does not mean that this element is not present.

A > indicates upper limit of measurement apparatus.

Inorganic emission factors for cupolas could not be obtained for most elements, however, the following emission factors are available:

- o Arsenic — 26.1 mg/Mg
- o Lead — 5×10^4 - 5.5×10^5 mg/Mg
- o Manganese — 1.25×10^5 mg/Mg
- o Copper — 8.5×10^2 mg/Mg

It is well known that toxic inorganics such as cadmium and mercury are emitted during melting processes, notably the cupola, if present in the raw materials charged into the furnace. However, emissions data are incomplete, with the result that these emission factors do not appear in this report.

Individual cupola emissions vary widely, depending on the blast rate, blast temperature, melt rate, the coke to melt ratio and raw material composition. Although emission factors are not applicable to all cupolas because of this wide variation, emissions data per specific cupola may be used to project future emissions in the presence of process changes.

The impurities in raw materials may contribute to higher emission factors for halogenated hydrocarbons in cupolas and EAFs. High emission readings for chromium, lead and mercury are probably related to scrap quality and cleanliness. Dirty, oily and low quality metallic raw materials fed to the furnace charge preparation process will result in more emissions from the melting unit.

Emission reduction efforts include the use of bag houses, wet scrubbers, and afterburners to reduce particulates, carbon monoxide (CO) and VOCs in cupola off-gases. Fabric filters are most effective in controlling cupola emissions, reducing manganese emissions from 250,000 to 300 mg/Mg. High energy scrubbers, impingement scrubbers and wet caps are used with less favorable results.

Use of gas for heat and graphite for carbon may reduce emissions due to coke, which contributes to organics and trace inorganics.

Electric Arc Furnaces

EAFs are also sources of organics and inorganics which are released both directly and indirectly. Uncontrolled, indirect emissions have been observed at very high levels for both organic and inorganic emissions.

Organic emission factors which are of primary concern are:

- o halogenated hydrocarbons 4.94 mg/Mg
- o aromatic hydrocarbons 3.41 mg/Mg
- o halogenated aromatics 3.41 mg/Mg
- o amines 0.40 mg/Mg

Inorganic emission factors for EAFs are:

- o tin 1,654 mg/Mg
- o antimony 3 mg/Mg
- o silver 36 mg/Mg
- o lead 323 mg/Mg
- o mercury 35 mg/Mg
- o boron 81 mg/Mg
- o fluorine 6,614 mg/Mg
- o chromium 97 mg/Mg
- o manganese 65 mg/Mg

Of these emission factors, chromium and lead are of primary concern.

Raw material quality control in this phase may help eliminate these emissions. Although uncontrolled manganese emissions from EAFs have been measured to be 75,000 mg/Mg. The use of a fabric filter can reduce these emissions by 99 percent.[9]

Electric Induction Furnaces

Electric induction furnaces using clean steel scrap produce particulate emissions comprised largely of iron oxides. High emissions from clean charge materials are due to cold charges. When contaminated charges are used, higher emission rates result. According to Shaw[10], contamination on charge materials may originate from:

- o rust on pig iron and scrap;
- o adhering dirt;

- o paint on scrap;
- o various deposits on scrap, e.g. oil and fuel breakdown products in internal combustion engine scrap, putty on scrap window frames, grease and paint on machinery scrap and engine parts;
- o molding materials adhering to returns and foundry scrap
- o carbon or graphite or other additions in powder form, or other additions containing powder;
- o cutting-oils on steel turnings and cast iron borings;
- o zinc on galvanized scrap, or contained in zinc die castings and,
- o iron and steel scrap containing nonferrous alloys or plating, e.g. bearing materials, brass inserts, soldered joints.

Dust emissions from electric induction furnaces are dependant upon the charge material composition, the melting method (cold charge or continuous), the melting rate, and the purity of the materials used.

The results available of measurements taken on furnaces using clean scrap show a range of total dust emissions from 3.12 x 10^4 to 1.82 x 10^5 mg/Mg metal melted.[10] Where contaminated charges are used, much higher emission rates are found.

The highest emissions occur during a cold charge, (usually the first charge of the day), in combination with a high percentage of uncleaned steel scrap. The emissions presented in Table 5 resulted from cold charge conditions using two-thirds returns and one-third uncleaned steel, at a 3.6 kg/hour melting rate, as measured by the CIATF Commission 4 Environmental Control.

Oxidation of the exposed molten metal surface produces the metallurgical smoke constituents in the table above. Molecular weight conversion may be used to determine the elemental metal content of the emissions.

TABLE 5. INDUCTION FURNACE EMISSIONS[10]

	Malleable Iron mg/Mg	Ductile Iron mg/Mg
SiO_2	6.5×10^4	1.3×10^4
ZnO	5.2×10^4	7.8×10^3
Al_2O_3	2.6×10^4	5.2×10^4
Cr_2O_3	1.3×10^3	2.0×10^3
CaO	6.5×10^2	2.6×10^2
MnO	1.3×10^3	1.3×10^3
MoO	2.6×10^2	2.6×10^1
TiO	1.3×10^2	5.2
NiO	1.3×10^2	1.3×10^2
B_2O_3	2.6×10^1	2.6
PbO	1.3×10^1	1.3×10^1
SnO_2	2.6	2.6
Bi_2O_3	2.6	2.6
V_2O_5	7.8	7.8
CuO	1.3	2.6
CoO	2.6	2.6
BaO	2.6	2.6

MOLD AND CORE PRODUCTION

In addition to organic binders, molds and cores may be held together in the desired shape by means of a cross-linked organic polymer network. This network (of polymers) undergoes thermal decomposition when exposed to the very high temperatures of

casting (typically 1400°C for iron castings). At these temperatures it is likely that pyrolysis of the chemical binder will produce a complex of free radicals which will recombine to form a wide range of chemical compounds having widely differing concentrations. In order to assess the environmental implications of these thermal-decomposition products, it is necessary to identify and quantify each of the compounds liberated. Each of the chemical binder systems gives rise to a number of different thermal-decomposition products, these products being characteristic of the different binder system.[11]

There are many different types of resins currently in use having diverse and toxic compositions. In spite of an intensive literature search, there are no data currently available for determining the toxic compounds in a particular resin which are emitted to the atmosphere, and to what extent these emissions occur. Toxic compounds are contained in resins and some are presumably emitted to the atmosphere but at an undetermined rate. Toxic compounds contained in resins may include:

- 4, 4' diphenylmethane diisocyanate
- kerosene
- polymethylene polyphenylene isocyanate
- catalytic reformer fractionator residue (petroleum derivative)
- methylene bis(phenylisocyanate) (MBI)
- diethylene glycol
- nickel soaps of fatty acids
- hydrotreated light distillates (petroleum derivative)
- formaldehyde
- phenol
- ethyl-3-epoxypropionate

The mix of pollutants liberated during core and mold making are a result of complex chemical reactions which are directly related to the quantity and composition chemicals present in the uncured resin.[11] Some foundry atmosphere contaminants commonly encountered during mold and core making are given in Table 6.

TABLE 6. SOME FOUNDRY-ATMOSPHERE CONTAMINANTS EVOLVED DURING MOLD AND CORE MAKING, CASTING, AND COOLING[11]

PROCESS	BINDER INGREDIENTS	POTENTIAL EMISSIONS
Shell	Ammonia Phenol Hexamethylene tetramine Stearates Fatty acids	Ammonia Aromatic hydrocarbons (benzene, toluene, xylene, etc.) Phenol and homologues (phenol, cresol, xylenol, etc.) Hexamethylene tetramine Other amines (e.g. trimethylamine) Hydrogen cyanide
Hot-box	Formaldehyde Phenol Urea Furfuryl alcohol	Aromatic hydrocarbons Phenol and homologues Ammonia Chlorinated hydrocarbons Hydrogen cyanide
Cold-set	Formaldehyde Furfuryl alcohol Phenol Benzene) Toluene) depends on catalyst Xylene)	Sulphur dioxide Hydrogen sulphide Mercaptans (e.g. methyl, ethyl mercaptan) Aromatic hydrocarbons Phenol and homologues Furan and homologues (furan, methyl furan, etc.) Carbonyl sulphide Carbon disulphide Aromatic sulphur compounds (Methyl ethyl ketone (Acetone - from SO2 - gassed system only)
Cold-box (amine-gassed)	Carbon dioxide Triethyl amine Dimethyl ethyl amine MDI Phenol Resin solvents (e.g. trimethyl benzene, isophorone) Naphthalene and homologues	Hydrogen cyanide Phenol and homologues Aromatic hydrocarbons Aniline and homologues (aniline, toluidine, etc.) Aliphatic amines Resin solvents (e.g. trimethyl benzene, isophorone) Isocyanates (e.g. methyl, phenyl isocyanate) Benzoquinolines

INOCULATION

Particulates, arsenic, chromium, halogenated hydrocarbons, and aromatic hydrocarbons are released in the inoculation process.

Inorganic emission factors pertaining to inoculation have been calculated for most elements. Those which are of primary concern are:

- o boron 56 mg/Mg
- o vanadium 56 mg/Mg
- o chromium 4 mg/Mg
- o arsenic 7.3 - 26.8 mg/Mg
- o lead 56 mg/Mg

Emission factors have been calculated for organics released in the inoculation process. Emission factors for halogenated hydrocarbons, 0.08 mg/Mg, and halogenated aromatics, 0.05 mg/Mg, are of primary importance.

POURING

The pouring (and cooling) process takes place after melting and inoculation. Emissions are related to mold size, mold composition, sand to metal ratio, pouring temperature and pouring rate. Organic compounds in the emissions due to the presence of sea coal and chemical binders in the sand are evolved into the surrounding environment during the pouring process. During this process, PM_{10} emission factors ranged from 2.5×10^{3} to 4.2×10^{6} mg/Mg (see Table 2).

Emissions during pouring include decomposition products of resins (CO, carbon dioxide (CO_2), phenols, hydrogen cyanide, ammonia, benzo(a)pyrene), other organic compounds, and particulate matter.

Emission factors have been calculated for inorganics evolved during the pouring process. The emission factor for nickel has been calculated at 25.3 mg/Mg, and for lead at 11.3 mg/Mg. Emission factors for boron, 11 mg/Mg and chromium, 66 mg/Mg were of primary concern.

Emission rates were measured for aliphatic hydrocarbons, halogenated hydrocarbons, aromatic hydrocarbons, fused aromatics, halogenated aromatics, heterocyclic N compounds, heterocyclic S compounds, alcohols, phenols, ketones, amines, silicones,

heterocyclic O compounds, nitroaromatics, ethers, aldehydes, phosphates, nitriles, alkyl S compounds, sulfonic acids, sulfoxides, amides, carboxylic acids, and esters.[5] The emission factors for these compounds are presented in Table 6.

Polynuclear aromatic organics (PNA) and fused aromatic organics are significant because these emissions may be present during cooling processes, where they can be formed and released, rather than in the pouring process. At present there are no emissions measurements for PNAs.

GREENSAND SHAKEOUT

The removal of castings from a sand mold releases moisture that has been trapped in the mold, dust from the sand and binders which have dried during pouring, and products of thermal decomposition of the chemical binders as they are exposed to air. Available emissions test data range from 8.5×10^4 mg/Mg to 9×10^6 mg/Mg of iron castings with an average of about 1.5×10^6 mg/Mg of iron castings. The data indicate a wide variation in the emission rate.[4]

As reported by Baldwin[4] the experiments of Bates and Scott[12] showed higher peak hydrocarbon concentrations (1500 ppm) during shakeout than during pouring and cooling, although the average concentrations were lower during shakeout. The particulate emissions during these laboratory tests were 55 percent higher with a 10 fold particle count increase over those of pouring. Toeniskoetter and Schafer[13] sampled many foundries for selected emissions from different binder systems. Their results show that the isocyanate concentration is frequently greater at shakeout than at the pouring station.

AIR TOXIC EMISSION FACTOR RATING

The emission factors presented in this report originated from diverse sources, and therefore have variable reliability (see Section 3 for rating scheme used in this report). The emission factors are rated according to source.

- All emission factors from Criteria Air Pollutant Emission Factors, prepared for the 1985 NAPAP Emissions Inventory, October 1988, are rated E.
- All emission factors calculated from the work by Baldwin, 1980; and Baldwin, 1982; are rated D.
- The emission factors from AP-42 for
  - VOC, NO_x, CO, and SO_x are rated B for all sources

- o PM_{10} from cupolas are rated C
- o PM_{10} from pouring are rated D
- o PM_{10} from EAF and Greensand Shakeout are rated E.

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APPENDIX A

AP-42 Section on Gray Iron Foundries

AP-42 Section

7.10 Gray Iron Foundries. A-2

(copied from Compilation of Air Pollutant Emission Factors,
Ap-42 Supplement B, Volume 1, Fourth Edition
U.S. Environmental Protection Agency, 1988)

7.10 GRAY IRON FOUNDRIES

7.10.1 General[1-5]

Gray iron foundries produce gray iron castings from scrap iron, pig iron and foundry returns by melting, alloying and molding. The production of gray iron castings involves a number of integrated steps, which are outlined in Figures 7.10-1 and 7.10-2. The four major production steps are raw materials handling and preparation, metal melting, mold and core production, and casting and finishing.

Raw Materials Handling And Preparation - Handling operations include receiving, unloading, storing and conveying of all raw materials for both furnace charging and mold and core preparation. The major groups of raw materials required for furnace charging are metallics, fluxes and fuels. Metallic raw materials include pig iron, iron and steel scrap, foundry returns and metal turnings. Fluxes include carbonates (limestone, dolomite), fluoride (fluorspar), and carbide compounds (calcium carbide).[4] Fuels include coal, oil, natural gas and coke. Coal, oil and natural gas are used to fire reverberatory furnaces. Coke, a derivative of coal, is used as a fuel in cupola furnaces. Carbon electrodes are required for electric arc furnaces.

As shown in Figures 7.10-1 and 7.10-2, the raw materials, metallics and fluxes are added to the melting furnaces directly. For electric induction furnaces, however, the scrap metal added to the furnace charge must first be pretreated to remove any grease and/or oil, which can cause explosions. Scrap metals may be degreased with solvents, by centrifugation, or by preheating to combust the organics.

In addition to the raw materials used to produce the molten metal, a variety of materials is needed to prepare the sand cores and molds that form the iron castings. Virgin sand, recycled sand and chemical additives are combined in a sand handling system typically comprising receiving areas, conveyors, storage silos and bins, mixers (sand mullers), core and mold making machines, shakeout grates, sand cleaners, and sand screening.

Raw materials are received in ships, railroad cars, trucks and containers, then transferred by truck, loaders and conveyors to both open piles and enclosed storage areas. When needed, the raw materials are transferred from storage to process areas by similar means.

Metal Melting - The furnace charge includes metallics, fluxes and fuels. The composition of the charge depends upon the specific metal characteristics required. Table 7.10-1 lists the different chemical compositions of typical irons produced. The three most common furnaces used in the gray iron foundry industry are cupolas, electric arc, and electric induction furnaces.

The cupola, which is the major type of furnace used in industry today, is typically a vertical cylindrical steel shell with either a refractory lined or water cooled inner wall. Refractory linings usually consist of silica brick, or dolomite or magnesium brick. Water cooled linings, which involve circulating

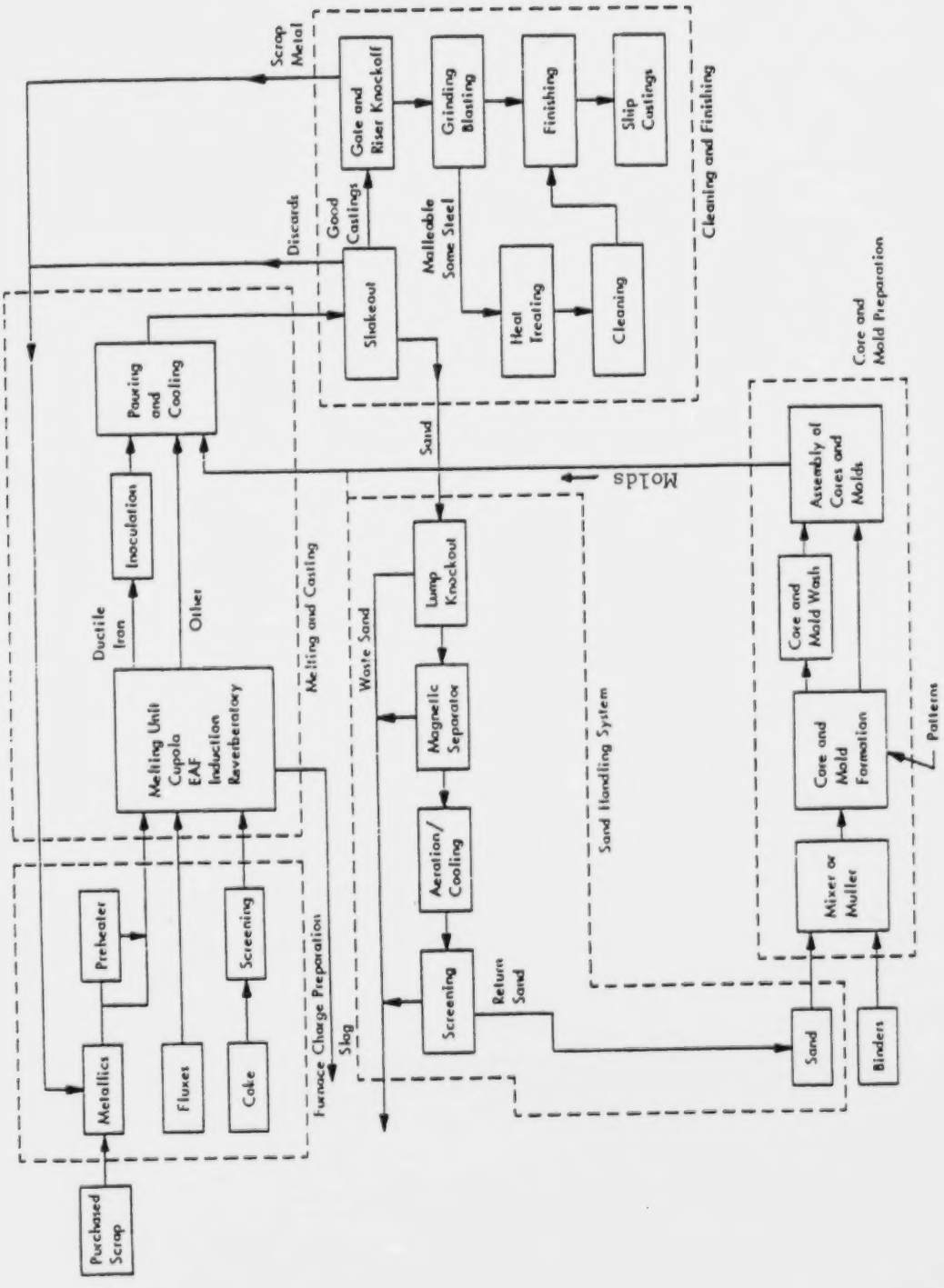

Figure 7.10-1. Typical iron foundry diagram.[2]

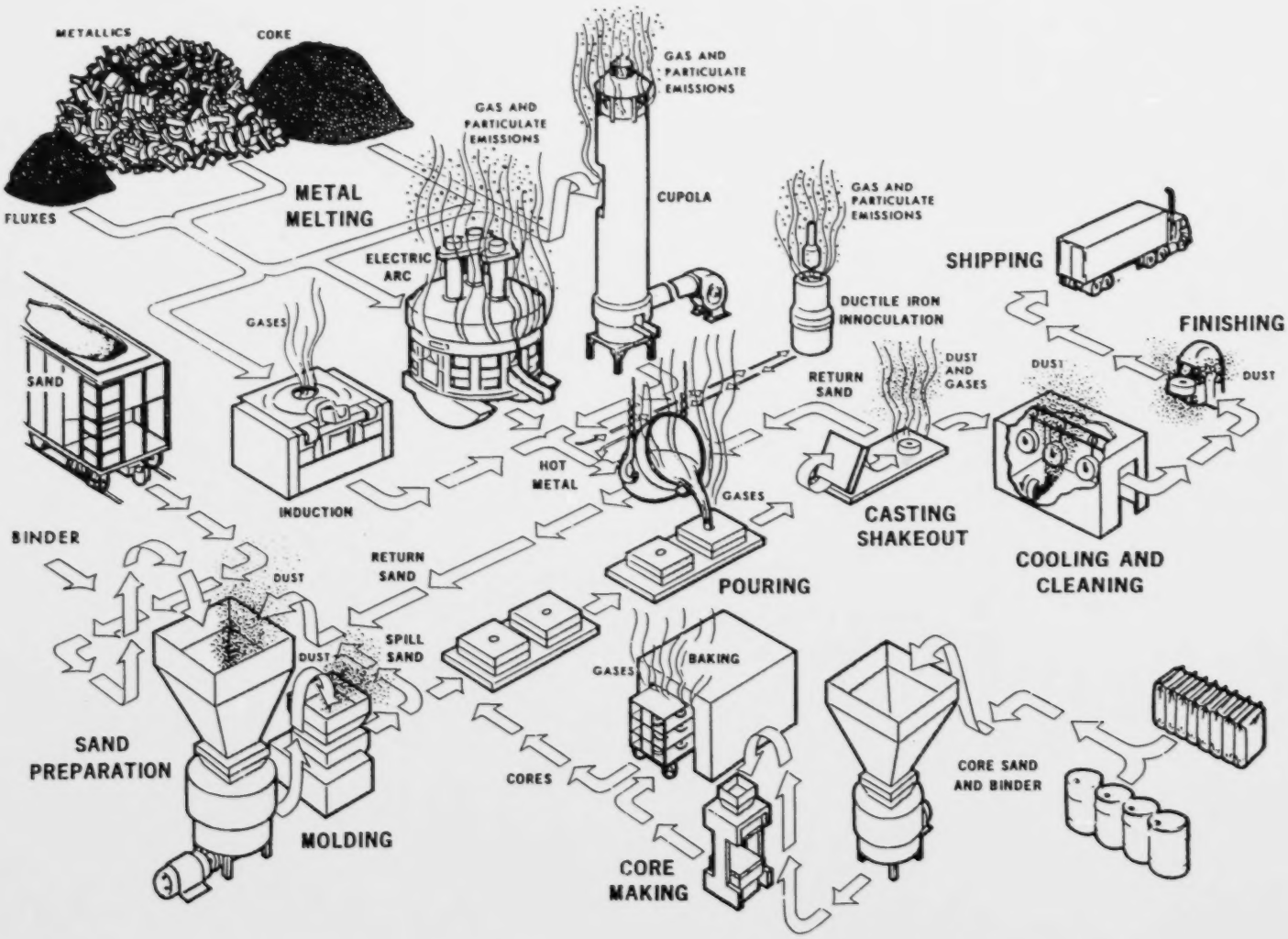

Figure 7.10-2. Emission points in a typical iron foundry.[2-3]

TABLE 7.10-1. CHEMICAL COMPOSITION OF FERROUS CASTINGS BY PERCENTAGE

Element	Gray iron	Malleable iron (as white iron)	Ductile iron[a]	Steel
Carbon	2.5 - 4.0	1.8 - 3.6	3.0 - 4.0	<2.0[b]
Silicon	1.0 - 3.0	0.5 - 1.9	1.4 - 2.0	0.2 - 0.8
Manganese	0.40 - 1.0	0.25 - 0.80	0.5 - 0.8	0.5 - 1.0
Sulfur	0.05 - 0.25	0.06 - 0.20	<0.12	<0.06
Phosphorus	0.05 - 1.0	0.06 - 0.18	<0.15	<0.05

[a]Necessary chemistry also includes 0.01 - 1.0% Mg.
[b]Steels are further classified by carbon content: low carbon, <0.20%; medium carbon, 0.20 - 0.50%; high carbon, >0.50%.

water around the outer steel shell, are used to protect the furnace wall from interior temperatures. The cupola is charged at the top with alternate layers of coke, metallics and fluxes.[2] The cupola is the only furnace type to use coke as a fuel; combustion air used to burn the coke is introduced through tuyeres located at the base of the cupola.[2] Cupolas use either cold blast air, air introduced at ambient temperature, or hot blast air with a regenerative system which utilizes heat from the cupola exhaust gases to preheat the combustion air.[2] Iron is melted by the burning coke and flows down the cupola. As the melt proceeds, new charges are added at the top. The flux removes nonmetallic impurities in the iron to form slag. Both the molten iron and the slag are removed through tap holes at the bottom of the cupola. Periodically, the heat period is completed, and the bottom of the cupola is opened to remove the remaining unburned material. Cupola capacities range from 1.0 to 27 megagrams per hour (1 to 30 tons per hour), with a few larger units approaching 90 megagrams per hour (100 tons per hour). Larger furnaces operate continuously and are inspected and cleaned at the end of each week or melting cycle.

Electric arc furnaces (EAF) are large, welded steel cylindrical vessels equipped with a removable roof through which three retractable carbon electrodes are inserted. The electrodes are lowered through the roof of the furnace and are energized by three phase alternating current, creating arcs that melt the metallic charge with their heat. Additional heat is produced by the resistance of the metal between the arc paths. The most common method of charging an electric arc furnace is by removing the roof and introducing the raw materials directly. Alternative methods include introducing the charge through a chute cut in the roof or through a side charging door in the furnace shell . Once the melting cycle is complete, the carbon electrodes are raised, and the roof is removed. The vessel is tilted, and the molten iron is poured into a ladle. Electric arc furnace capacities range from 0.23 to 59 megagrams (0.25 to 65 tons). Nine to 11 pounds of electrode are consumed per ton of metal melted.

Electric induction furnaces are either cylindrical or cup shaped refractory lined vessels that are surrounded by electrical coils which, when energized with high frequency alternating current, produce a fluctuating electromagnetic field to heat the metal charge. For safety reasons, the scrap metal added to the furnace charge is cleaned and heated before being introduced into the furnace. Any oil or moisture on the scrap could cause an explosion in the furnace. Induction furnaces are kept closed except when charging, skimming and tapping. The molten metal is tapped by tilting and pouring through a hole in the side of the vessel. Induction furnaces also may be used for metal refining in conjunction with melting in other furnaces and for holding and superheating the molten metal before pouring (casting).

The basic melting process operations are 1) furnace charging, in which metal, scrap, alloys, carbon, and flux are added to the furnace; 2) melting, during which the furnace remains closed; 3) backcharging, which involves the addition of more metal and alloys, as needed; 4) refining and treating, during which the chemical composition is adjusted to meet product specifications; 5) slag removing; and 6) tapping molten metal into a ladle or directly into molds.

Mold And Core Production - Molds are forms used to shape the exterior of castings. Cores are molded sand shapes used to make the internal voids in castings. Cores are made by mixing sand with organic binders, molding the sand into a core, and baking the core in an oven. Molds are prepared of a mixture of wet sand, clay and organic additives to make the mold shapes, which are usually dried with hot air. Cold setting binders are being used more frequently in both core and mold production. The green sand mold, the most common type, uses moist sand mixed with 4 to 6 percent clay (bentonite) for bonding. The mixture is 4 to 5 percent water content. Added to the mixture, to prevent casting defects from sand expansion when the hot metal is poured, is about 5 percent organic material, such as sea coal (a pulverized high volatility bituminous coal), wood flour, oat hulls, pitch or similar organic matter.

Common types of gray iron cores are:

- Oil core, with typical sand binder percents of 1.0 core oil, 1.0 cereal, and 0 to 1 pitch or resin. Cured by oven baking at 205 to 315°C (400 to 600°F), for 1 to 2 hours.

- Shell core, with sand binder typically 3 to 5 percent phenolic and/or urea formaldehyde, with hexamine activator. Cured as a thin layer on a heated metal pattern at 205 to 315°C (400 to 600°F), for 1 to 3 minutes.

- Hot box core, with sand binder typically 3 to 5 percent furan resin, with phosphoric acid activator. Cured as a solid core in a heated metal pattern at 205 to 315°C (400 to 600°F), for 0.5 to 1.5 minutes.

- Cold set core, with typical sand binder percents of 3 to 5 furan resin, with phosphoric acid activator; or 1 to 2 core oil, with phosphoric acid activator. Hardens in the core box. Cured for 0.5 to 3 hours.

- Cold box core, with sand binder typically 1 to 3 percent of each of two resins, activated by a nitrogen diluted gas. Hardens when the green core is gassed in the box with polyisocyanate in air. Cured for 10 to 30 seconds.

Used sand from castings shakeout is recycled to the sand preparation area and cleaned to remove any clay or carbonaceous buildup. The sand is then screened and reused to make new molds. Because of process losses and discard of a certain amount of sand because of contamination, makeup sand is added.

Casting And Finishing - After the melting process, molten metal is tapped from the furnace. Molten iron produced in cupolas is tapped from the bottom of the furnace into a trough, thence into a ladle. Iron produced in electric arc and induction furnaces is poured directly into a ladle by tilting the furnace. At this point, the molten iron may be treated with magnesium to produce ductile iron. The magnesium reacts with the molten iron to nodularize the carbon in the molten metal, giving the iron less brittleness. At times, the molten metal may be inoculated with graphite to adjust carbon content. The treated molten iron is then ladled into molds and transported to a cooling area, where it solidifies in the mold and is allowed to cool further before separation (shakeout) from the mold and core sand. In larger, more mechanized foundries, the molds are conveyed automatically through a cooling tunnel. In simpler foundries, molds are placed on an open floor space, and the molten iron is poured into the molds and allowed to cool partially. Then the molds are placed on a vibrating grid to shake the mold and core sand loose from the casting. In the simpler foundries, molds, core sand and castings are separated manually, and the sand from the mold and core is then returned to the sand handling area.

When castings have cooled, any unwanted appendages, such as spurs, gates, and risers, are removed. These appendages are removed with oxygen torch, abrasive band saw, or friction cutting tools. Hand hammers may be used, in less mechanized foundries. to knock the appendages off. After this, the castings are subjected to abrasive blast cleaning and/or tumbling to remove any remaining mold sand or scale.

Another step in the metal melting process involves removing the slag in the furnace through a tapping hole or door. Since the slag is lighter than molten iron, it remains atop the molten iron and can be raked or poured out of cupola furnaces through the slag hole located above the level of the molten iron. Electric arc and induction furnaces are tilted backwards, and their slag is removed through a slag door.

7.10.2 Emissions And Controls

Emissions from the raw materials handling operations are fugitive particulate generated from the receiving, unloading, storage and conveying of raw materials. These emissions are controlled by enclosing the major emission points (e. g., conveyor belt transfer points) and routing air from the enclosures through fabric filters or wet collectors. Figure 7.10-2 shows emission points and types of emissions from a typical foundry.

Scrap preparation with heat will emit smoke, organic compounds and carbon monoxide, and scrap preparation with solvent degreasers will emit organics. Catalytic incinerators and afterburners can control about 95 percent of organic and carbon monoxide emissions. (See Section 4.6, Solvent Degreasing.)

Emissions released from the melting furnaces include particulate matter, carbon monoxide, organic compounds, sulfur dioxide, nitrogen oxides and small quantities of chloride and fluoride compounds. The particulates, chlorides and

fluorides are generated from incomplete combustion of coke, carbon additives, flux additions, and dirt and scale on the scrap charge. Organic material on the scrap, the consumption of coke in the furnace, and the furnace temperature all affect the amount of carbon monoxide generated. Sulfur dioxide emissions, characteristic of cupola furnaces, are attributable to sulfur in the coke. Fine particulate fumes emitted from the melting furnaces come from the condensation of volatilized metal and metal oxides.

During melting in an electric arc furnace, particulate emissions are generated by the vaporization of iron and the transformation of mineral additives. These emissions occur as metallic and mineral oxides. Carbon monoxide emissions come from the combustion of the graphite lost from the electrodes and the carbon added to the charge. Hydrocarbons may come from vaporization and partial combustion of any oil remaining on the scrap iron added to the furnace charge.

The highest concentrations of furnace emissions occur during charging, backcharging, alloying, slag removal, and tapping operations, because furnace lids and doors are opened. Generally, these emissions escape into the furnace building or are collected and vented through roof openings. Emission controls for melting and refining operations usually involve venting the furnace gases and fumes directly to a control device. Controls for fugitive furnace emissions include canopy hoods or special hoods near the furnace doors and tapping hoods to capture emissions and route them to emission control systems.

High energy scrubbers and baghouses (fabric filters) are used to control particulate emissions from cupolas and electric arc furnaces in this country. When properly designed and maintained, these control devices can achieve respective efficiencies of 95 and 98 percent. A cupola with such controls typically has an afterburner with up to 95 percent efficiency, located in the furnace stack, to oxidize carbon monoxide and to burn organic fumes, tars and oils. Reducing these contaminants protects the particulate control device from possible plugging and explosion. Because induction furnaces emit negligible amounts of hydrocarbon and carbon monoxide emissions, and relatively little particulate, they are usually uncontrolled.[2]

The major pollutant emitted in mold and core production operations is particulate from sand reclaiming, sand preparation, sand mixing with binders and additives, and mold and core forming. Organics, carbon monoxide and particulate are emitted from core baking, and organic emissions from mold drying. Baghouses and high energy scrubbers generally are used to control particulate from mold and core production. Afterburners and catalytic incinerators can be used to control organics and carbon monoxide emissions.

Particulate emissions are generated during the treatment and inoculation of molten iron before pouring. For example, during the addition of magnesium to molten metal to produce ductile iron, the reaction between the magnesium and molten iron is very violent, accompanied by emissions of magnesium oxides and metallic fumes. Emissions from pouring consist of hot metal fumes, and carbon monoxide, organic compounds and particulate evolved from the mold and core materials contacting the molten iron. Emissions from pouring normally are captured by a collection system and vented, either controlled or uncontrolled, to the atmosphere. Emissions continue as the molds cool. A significant quantity of particulate is also generated during the casting shakeout operation. These fugitive emissions must be captured, and they usually are controlled by

either high energy scrubbers or bag filters.

Finishing operations emit large, coarse particles during the removal of burrs, risers and gates, and during shot blast cleaning. These emissions are easily controlled by cyclones and baghouses.

Emission factors for total particulate from gray iron furnaces are presented in Table 7.10-2, and emission factors for gaseous and lead pollutants are given in Table 7.10-3. Tables 7.10-4 and 7.10-5, respectively, give factors for ancillary process operations and fugitive sources and for specific particle sizes. Particle size factors and distributions are presented also in Figures 7.10-3 through 7.10-8.

TABLE 7.10-2. EMISSION FACTORS FOR GRAY IRON FURNACES[a]

Process	Control device	Total particulate		Emission Factor Rating
		kg/Mg	lb/ton	
Cupola	Uncontrolled[b]	6.9	13.8	C
	Scrubber[c]	1.6	3.1	C
	Venturi scrubber[d]	1.5	3.0	C
	Electrostatic precipitator[e]	0.7	1.4	E
	Baghouse[f]	0.3	0.7	C
	Single wet cap[g]	4.0	8.0	B
	Impingement scrubber[g]	2.5	5.0	B
	High energy scrubber[g]	0.4	0.8	B
Electric arc furnace	Uncontrolled[h]	6.3	12.7	C
	Baghouse[j]	0.2	0.4	C
Electric induction furnace	Uncontrolled[k]	0.5	0.9	D
	Baghouse[m]	0.1	0.2	E
Reverberatory	Uncontrolled[n]	1.1	2.1	D
	Baghouse[m]	0.1	0.2	E

[a]Expressed as weight of pollutant/weight of gray iron produced.
[b]References 1,7,9-10.
[c]References 12,15. Includes averages for wet cap and other scrubber types not already listed.
[d]References 12,17,19.
[e]References 8,11.
[f]References 12-14.
[g]References 8,11,29-30.
[h]References 1,6,23.
[j]References 6,23-24.
[k]References 1,12. For metal melting only.
[m]Reference 4.
[n]Reference 1.

TABLE 7.10-3. GASEOUS AND LEAD EMISSION FACTORS FOR GRAY IRON FOUNDRIES[a]

EMISSION FACTOR RATING: B

Furnace type	Carbon monoxide		Sulfur dioxide		Nitrogen oxides		Volatile organic compounds		Lead[b]	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Cupola										
Uncontrolled	73[c]	145[c]	0.6S[d]	1.2S[d]	-	-	-	-	0.05-0.6	0.1-1.1
High energy scrubber	-	-	0.3S[d]	0.6S[d]	-	-	-	-	-	-
Electric arc[e]	0.5-19	1-37	Neg	Neg	0.02-0.3	0.04-0.6	0.03-0.15	0.06-0.3	-	-
Electric induction[f]	Neg	Neg	Neg	Neg	-	-	-	-	0.005-0.05	0.009-0.1
Reverberatory	-	-	-	-	-	-	-	-	0.006-0.07	0.012-0.14

[a]Expressed as weight of pollutant/weight of gray iron produced. Dash = no data. Neg = negligible.
[b]References 11,31,34.
[c]Reference 2.
[d]Reference 4. S = % sulfur in the coke. Assumes 30% of sulfur is converted to SO_2.
[e]Reference 4,6.
[f]References 8,11,29-30.

TABLE 7.10-4. PARTICULATE EMISSION FACTORS FOR ANCILLARY PROCESS OPERATIONS AND FUGITIVE SOURCES AT GRAY IRON FOUNDRIES

Process	Control device	Total emission factor		Emitted to work environment		Emitted to atmosphere		Emission Factor Rating
		kg/Mg metal	lb/ton metal	kg/Mg metal	lb/ton metal	kg/Mg metal	lb/ton metal	
Scrap and charge handling, heating[b]	Uncontrolled	0.3	0.6	0.25	0.5	0.1	0.2	D
Magnesium treatment[c]	Uncontrolled	0.9	1.8	0.9	1.8	0.2	0.4	E
Inoculation[d]	Uncontrolled	1.5 - 2.5	3 - 5	-	-	-	-	D
Pouring, cooling[e]	Uncontrolled	2.1	4.2					D
Shakeout[f]	Uncontrolled[c]	1.6	3.2					D
Cleaning, finishing[b]	Uncontrolled	8.5	17	0.15	0.3	0.05	0.1	D
Sand handling[g]	Uncontrolled[c]	1.8	3.6	-	-	-	-	E
	Scrubber[h]	0.023	0.046	-	-	-	-	D
	Baghouse[j]	0.10	0.20	-	-	-	-	D
Core making, baking[b]	Uncontrolled	0.6	1.1	0.6	1.1	0.6	1.1	D

[a]Expressed as weight of pollutant/weight of gray iron produced, except as noted. Dash = no data.
[b]Reference 4.
[c]References 1,4.
[d]Reference 35.
[e]References 1,3,25.
[f]Reference 1.
[g]Kg of sand/Mg of sand handled.
[h]References 12,27.
[j]Reference 12.

TABLE 7.10-5. PARTICLE SIZE DISTRIBUTION DATA AND EMISSION FACTORS FOR GRAY IRON FOUNDRIES[a]

Source	Emission Factor Rating	Particle size (um)	Cumulative mass % ≤ stated size[b]	Cumulative mass emission factor kg/Mg metal	Cumulative mass emission factor lb/ton metal
Cupola Furnace[b] Uncontrolled	C	0.5	44.3	3.1	6.1
		1.0	69.1	4.8	9.5
		2.0	79.6	5.5	11.0
		2.5	84.0	5.8	11.6
		5.0	90.1	6.2	12.4
		10.0	90.1	6.2	12.4
		15.0	90.6	6.3	12.5
			100.0	6.9	13.8
Controlled by baghouse	E	0.5	83.4	0.33	0.58
		1.0	91.5	0.37	0.64
		2.0	94.2	0.38	0.66
		2.5	94.9	0.38	0.66
		5.0	94.9	0.38	0.66
		10.0	94.9	0.38	0.66
		15.0	95.0	0.38	0.67
			100.0	0.4	0.7
Controlled by venturi scrubber[c]	C	0.5	56.0	0.84	1.7
		1.0	70.2	1.05	2.1
		2.0	77.4	1.16	2.3
		2.5	77.7	1.17	2.3
		5.0	77.7	1.17	2.3
		10.0	77.7	1.17	2.3
		15.0	77.7	1.17	2.3
			100.0	1.5	3.0

TABLE 7.10-5 (cont.).

Process	Particle size (um)	Cumulative mass % ≤ stated size[b]	Cumulative mass emission factor kg/Mg metal	Cumulative mass emission factor lb/ton metal	Emission Factor Rating
Electric arc furnace[d] Uncontrolled	1.0	13.0	0.8	1.6	E
	2.0	57.5	3.7	7.3	
	5.0	82.0	5.2	10.4	
	10.0	90.0	5.8	11.4	
	15.0	93.5	6.0	11.9	
		100.0	6.4	12.7	
Pouring, cooling[b] Uncontrolled	0.5	d	-	-	D
	1.0	19.0	0.40	0.80	
	2.0	20.0	0.42	0.84	
	2.5	24.0	0.50	1.00	
	5.0	34.0	0.71	1.43	
	10.0	49.0	1.03	2.06	
	15.0	72.0	1.51	3.02	
		100.0	2.1	4.2	
Shakeout[b] Uncontrolled	0.5	23.0	0.37	0.74	E
	1.0	37.0	0.59	1.18	
	2.0	41.0	0.66	1.31	
	2.5	42.0	0.67	1.34	
	5.0	44.0	0.70	1.41	
	10.0	70.0	1.12	2.24	
	15.0	99.9	1.60	3.20	
		100.0	1.60	3.20	

[a]Expressed as weight of pollutant/weight of metal melted (produced). Dash = no data. Mass emission rate data available in Tables 7.10-2 and 7.10-4 to calculate size specific emission factors.
[b]References 13,21-22,25-26. See Figures 7.10-3 through 7.10-8.
[c]Pressure drop across venturi: approx. 102 inches of water.
[d]Reference 3, Exhibit VI-15. Averaged from data on two foundries. Because original test data could not be obtained, Emission Factor Rating is E.

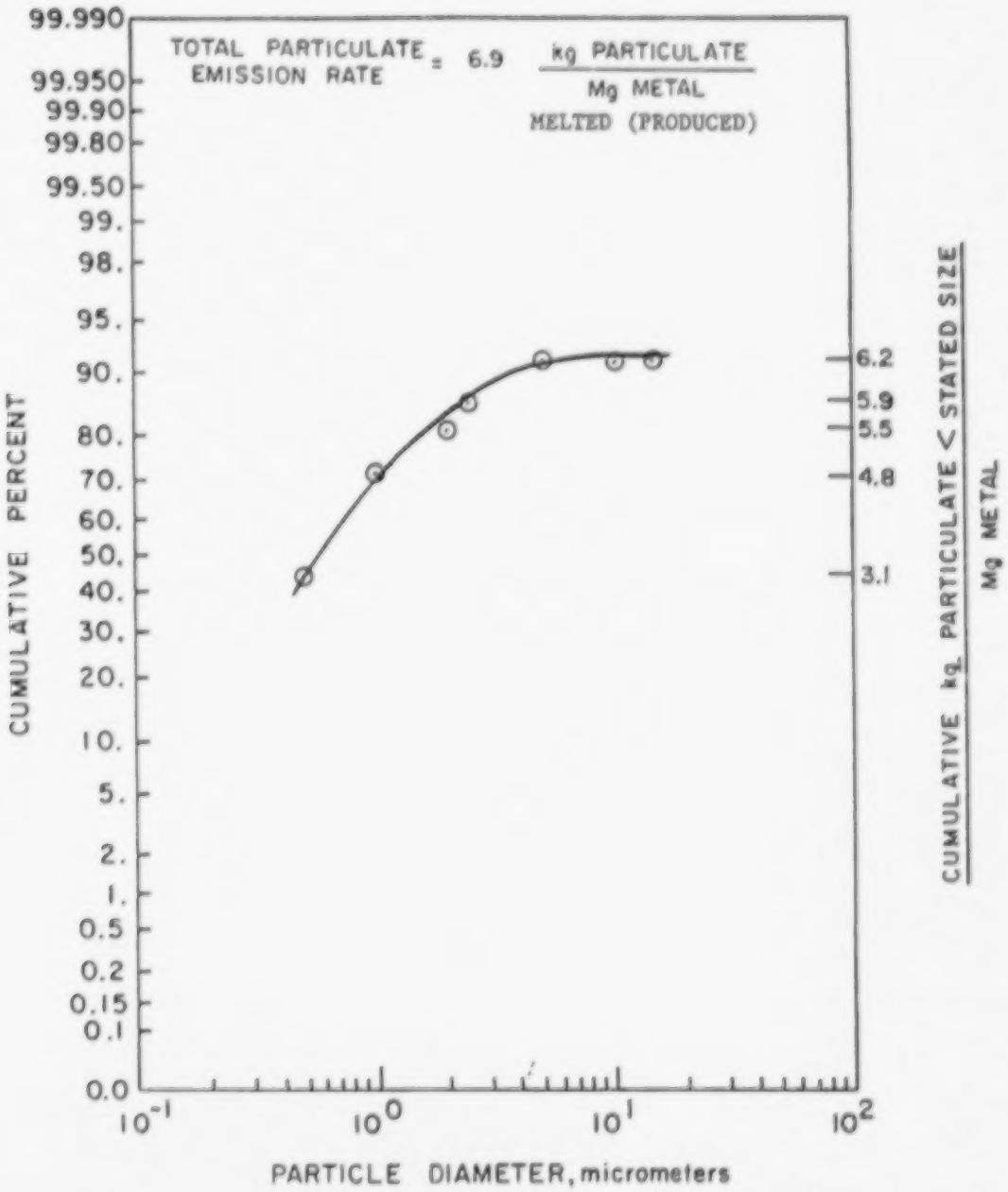

Figure 7.10-3. Particle size distribution for uncontrolled cupola.[21-22]

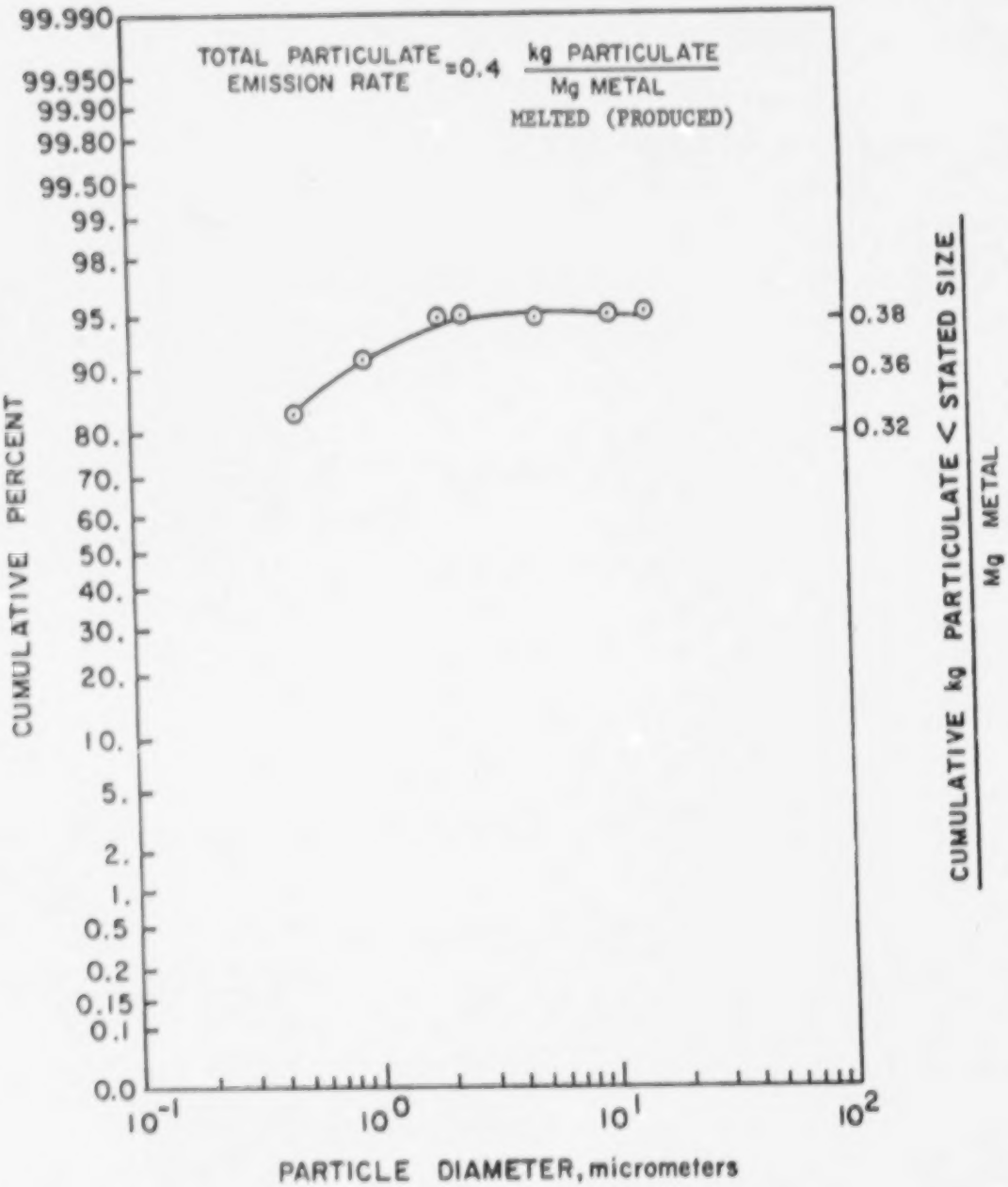

Figure 7.10-4. Particle size distribution for baghouse controlled cupola.[13]

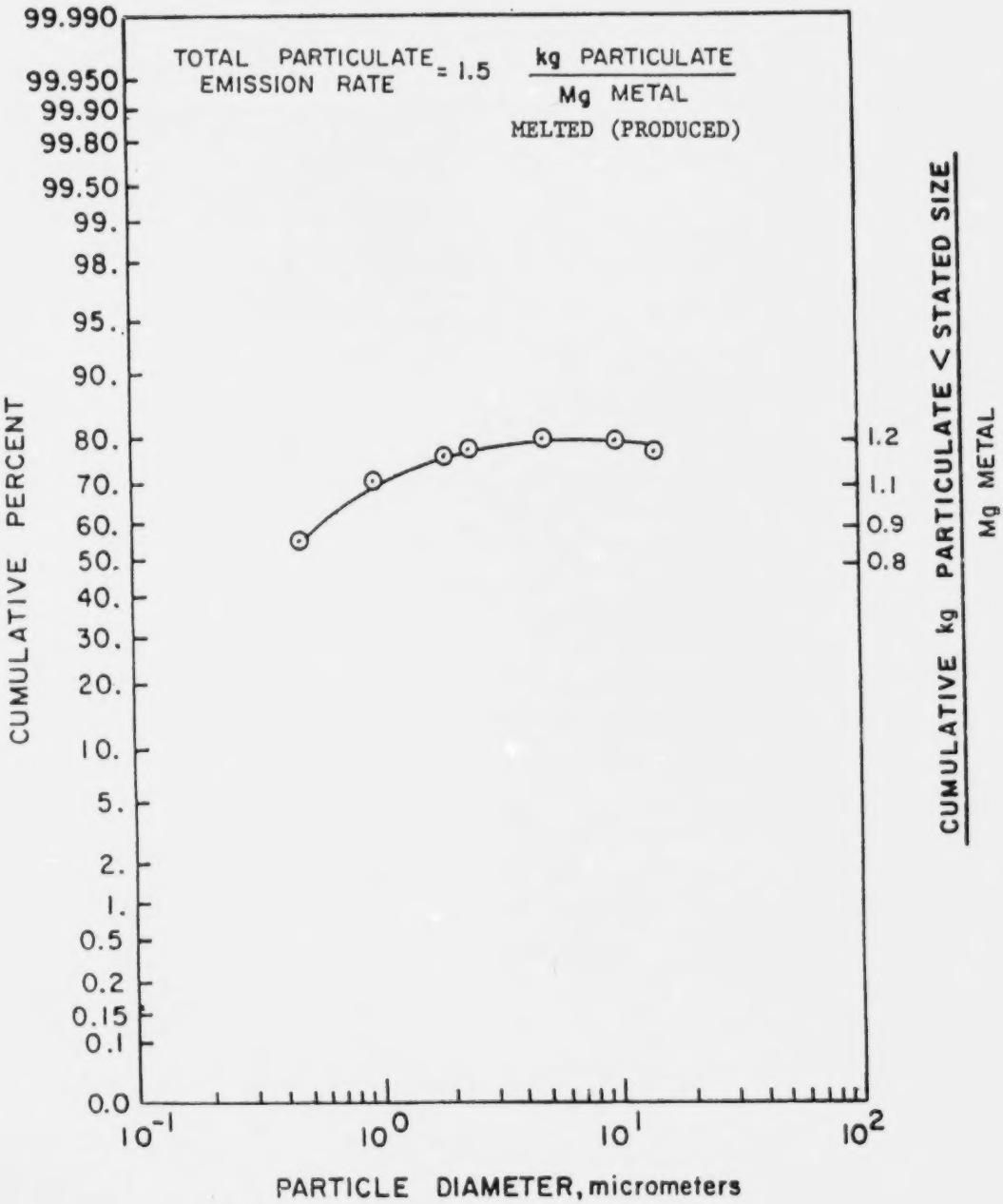

Figure 7.10-5. Particle size distribution for venturi scrubber controlled cupola.[21-22]

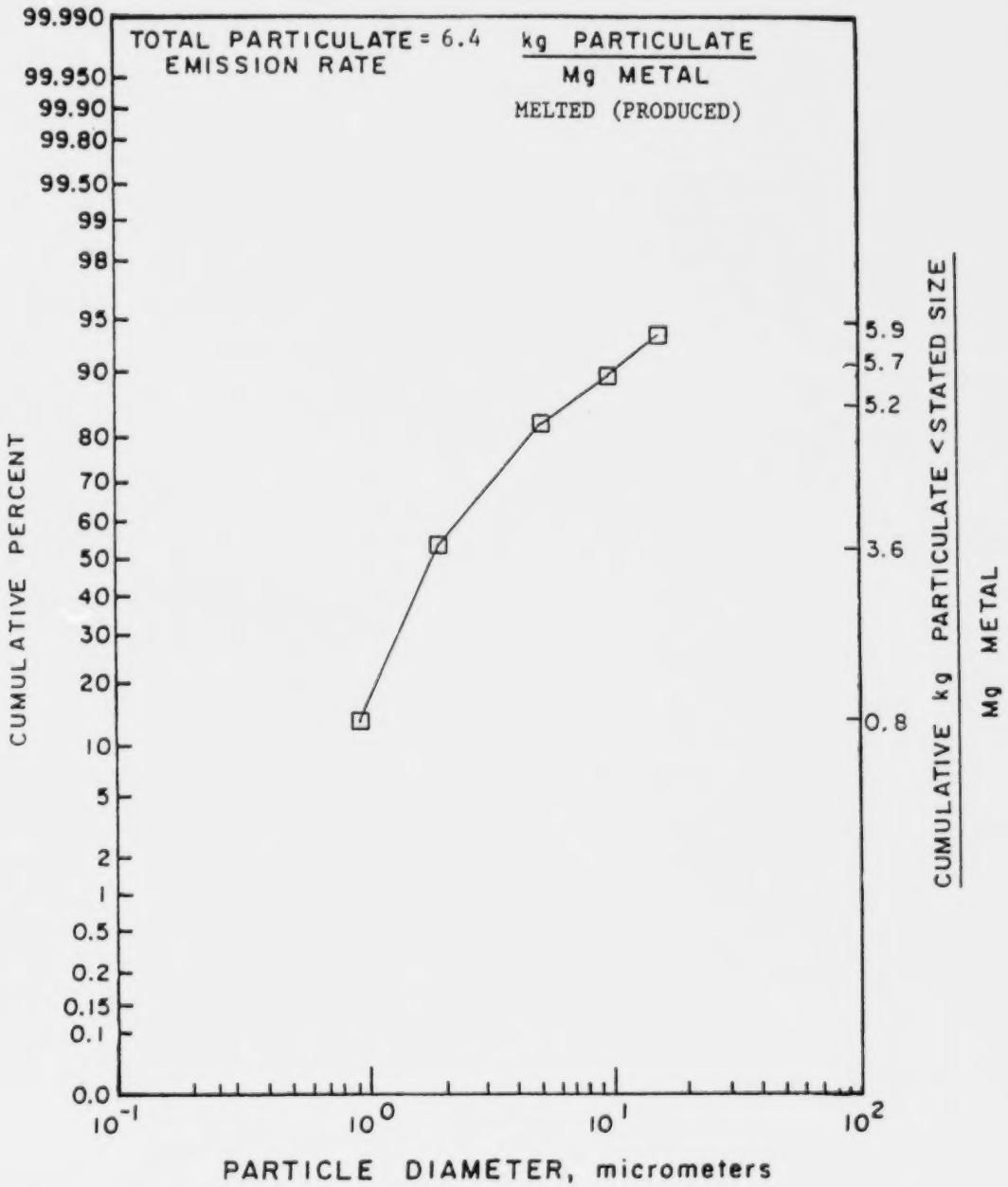

Figure 7.10-6. Particle size distribution for uncontrolled electric arc furnace.[3]

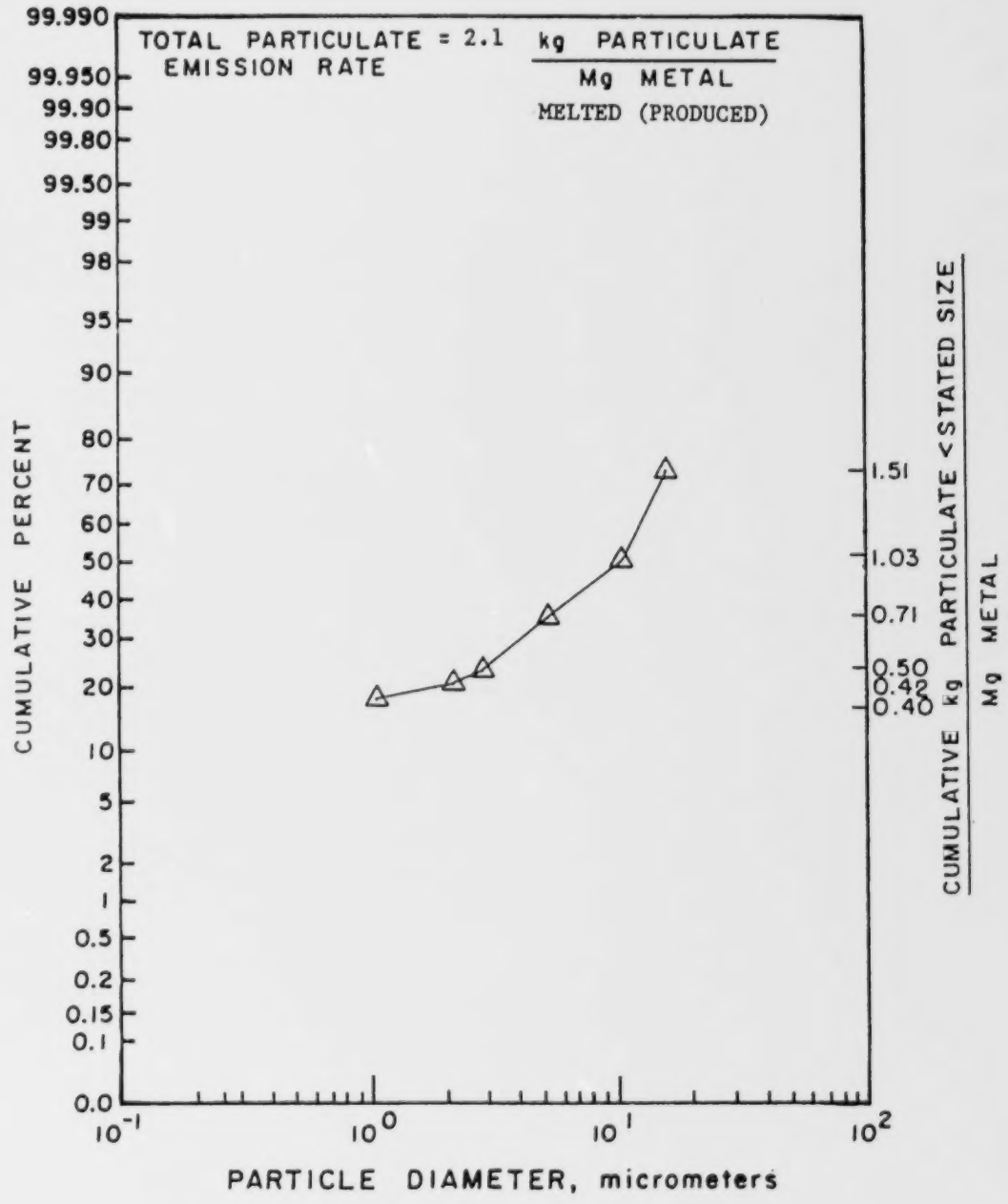

Figure 7.10-7. Particle size distribution for uncontrolled pouring and cooling.[25]

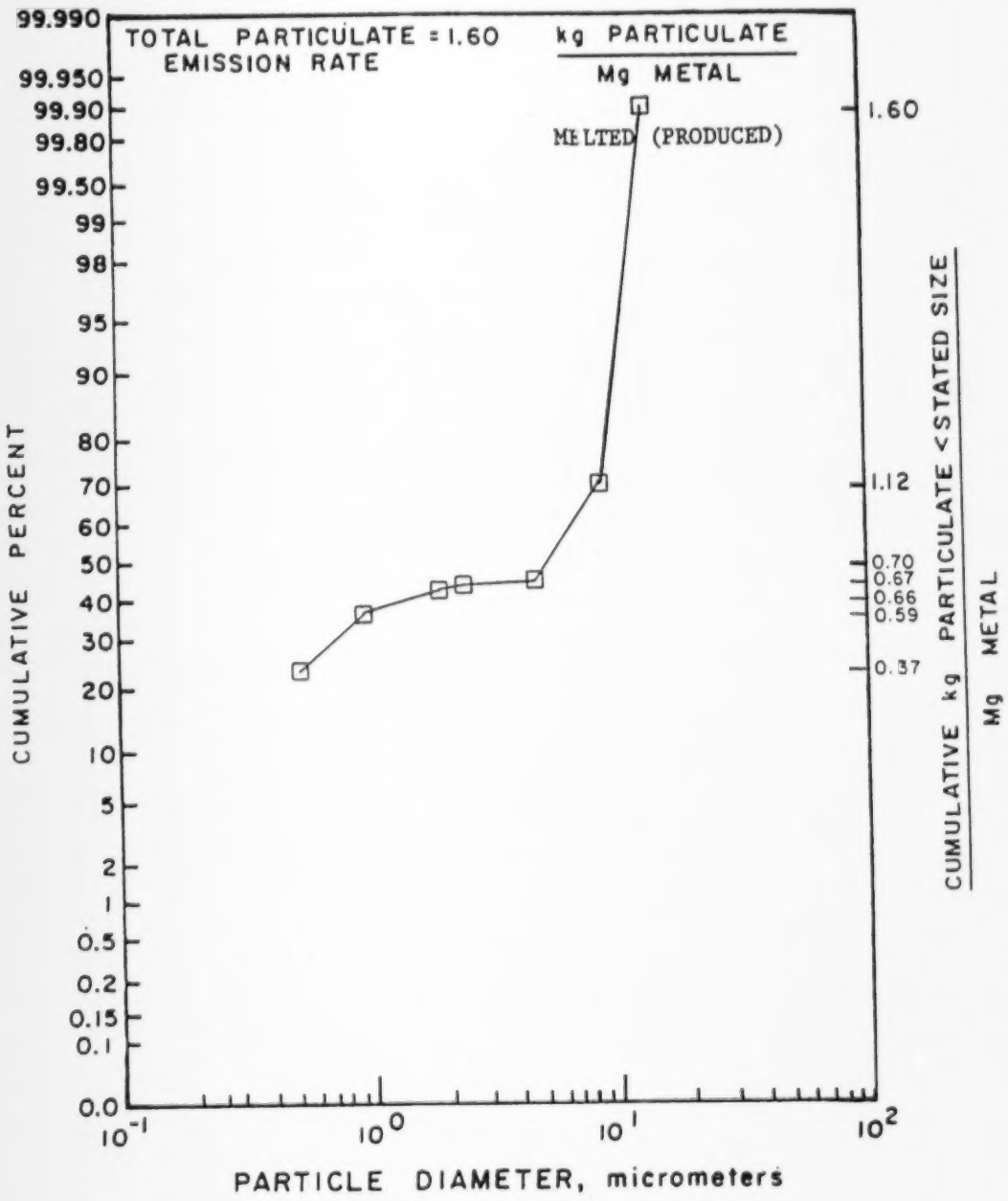

Figure 7.10-8. Particle size distribution for uncontrolled shakeout.[26]

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Appendix B. Toxic Air Pollutant Emission Factors for Iron Foundries[9]

SIC CODE	EMISSION SOURCE	SCC	POLLUTANT	CAS NUMBER	EMISSION FACTOR	NOTES
332	Cupola	30400301	Manganese	7439965	0.25 lb/ton of iron	Uncontrolled, calculated based on engineering judgement
332	Cupola	30400301	Manganese	7439965	0.12 lb/ton of iron	Controlled by wet cap, calculated based on engineering judgement
332	Cupola	30400301	Manganese	7439965	0.075 lb/ton of iron	Controlled by impingement scrubber, calculated based on engineering judgement
332	Cupola	30400301	Manganese	7439965	0.012 lb/ton of iron	Controlled by high energy scrubber, calculated based on engineering judgement
332	Cupola	30400301	Manganese	7439965	0.003 lb/ton of iron.	Controlled by fabric filter, calculated based on engineering judgement
332	Induction furnace	30400303	Manganese	7439965	0.0225 lb/ton of iron	Uncontrolled, calculated based on engineering judgement
332	Electric arc furnace	30400304	Manganese	7439965	0.15 lb/ton of iron	Uncontrolled, calculated based on engineering judgement
332	Electric arc furnace	30400304	Manganese	7439965	0.0015 lb/ton of iron	Controlled by fabric filter (99%), calculated based on engineering judgement
3321	Cupola	30400301	Copper	7440508	0.0017 kg/Mg grey iron produced	Uncontrolled, copper content 0.02%, PM factors

Appendix C. Criteria Air Pollutant Emission Factors for Gray Iron Foundries [3]

SCC	Process Name	PART Lbs/Unit	PM10 Lbs/Unit	SOx Lbs/Unit	NOx Lbs/Unit	VOC Lbs/Unit	CO Lbs/Unit	LEAD Lbs/Unit	UNITS
3-04-003-01	Cupola	13.8	12.4	0.9	0.1	0.18	145.0	0.51	Tons of Metal Charged
3-04-003-02	Reverberatory Furnace	2.1	1.7	180.0	5.8	0.15	0.0	0.06	Tons of Metal Charged
3-04-003-03	Electric Induction Furnace	0.9	0.86	0.0	0.0	0.0	0.0	0.0425	Tons of Metal Charged
3-04-003-04	Electric Arc Furnace	12.7	11.4	0.25	0.32	0.18	19.0	---	Tons of Metal Charged
3-04-003-05	Annealing Operation	---	---	---	1.0	0.1	---	---	Tons Processed
3-04-003-10	Inoculation	4.0	3.2	---	---	0.005	---	---	Tons of Metal Inoculated
3-04-003-15	Charge Handling	0.6	0.36	0.0	0.0	0.0	---	---	Tons of Metal Charged
3-04-003-20	Pouring/Casting	2.8	5.0	0.02	0.01	0.14	---	---	Tons of Metal Charged
3-04-003-25	Castings Cooling	1.4	10.0	0.0	0.0	0.0	---	---	Tons of Metal Charged
3-04-003-31	Casting Shakeout	3.2	2.24	0.0	0.0	1.2	---	---	Tons of Metal Charged
3-04-003-32	Casting Knock Out	---	---	0.0	0.0	1.2	---	---	Tons Sand Handled
3-04-003-33	Shakeout Machine	---	---	0.0	0.0	1.2	---	---	Tons Sand Handled
3-04-003-40	Grinding/Cleaning	17.0	1.7	0.0	0.0	0.0	0.0	---	Tons of Metal Charged
3-04-003-41	Casting Cleaning/ Tumblers	---	---	0.0	0.0	0.0	---	---	Tons Castings Cleaned
3-04-003-42	Casting Cleaning/ Chippers	---	---	0.0	0.0	0.0	---	---	Tons Castings Cleaned
3-04-003-50	Sand Grinding / Handling	0.65 (c)	0.54	0.0	0.0	0.0	---	--	Tons Sand Handled
3-04-003-51	Core Ovens	2.71 (c)	2.22	0.32	0.5	0.0008	---	---	Tons Sand Handled
3-04-003-52	Sand Grinding / Handling	40.0	6.0	0.0	0.0	0.0	---	---	Tons of Metal Charged
3-04-003-53	Core Ovens	3.6	---	0.32	0.5	0.0008	---	---	Tons of Metal Charged
3-04-003-54	Core Ovens	---	---	0.33	0.5	0.0008	---	---	Gallons of Core Oil Used
3-04-003-55	Sand Dryer	---	---	0.0	1.6	0.004	---	---	Tons Sand Handled
3-04-003-56	Sand Silo	---	---	0.0	0.0	0.0	---	---	Tons Sand Handled
3-04-003-57	Conveyors/Elevators	---	---	0.0	0.0	0.0	---	---	Tons Sand Handled
3-04-003-58	Sand Screens	---	---	0.0	0.0	0.0	---	---	Tons Sand Handled
3-04-003-60	Castings Finishing	0.01 (c)	0.0045	0.0	0.0	0.0	---	---	Tons of Metal Charged
3-04-003-70	Shell Core Machine	---	---	0.32	0.5	0.0008	---	---	Tons of Cores Produced
3-04-003-71	Core Machines/Other	---	---	0.32	0.5	0.0008	---	---	Tons of Cores Produced
3-04-003-98	Other Not Classified	---	---	---	---	---	---	---	Gallons
3-04-003-99	Other Not Classified	XXX	XXX	XXX	XXX	XXX	XXX	XXX	Tons of Metal Charged

Appendix D. Threshold Limit Values and Biological Exposure Indices for 1989 - 1990[14]

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Particle Size-Selective Sampling Criteria for Airborne Particulate Matter

For chemical substances present in inhaled air as suspensions of solid particles or droplets, the potential hazard depends on particle size as well as mass concentration because of: 1) effects of particle size on deposition site within the respiratory tract, and 2) the tendency for many occupational diseases to be associated with material deposited in particular regions of the respiratory tract.

ACGIH has recommended particle size-selective TLVs for crystalline silica for many years in recognition of the well established association between silicosis and respirable mass concentrations. It now has embarked on a re-examination of other chemical substances encountered in particulate form in occupational environments with the objective of defining: 1) the size-fraction most closely associated for each substance with the health effect of concern, and 2) the mass concentration within that size fraction which should represent the TLV.

The Particle Size-Selective TLVs (PSS-TLVs) will be expressed in three forms, e.g.,

a. *Inspirable Particulate Mass TLVs (IPM-TLVs)* for those materials which are hazardous when deposited anywhere in the respiratory tract.
b. *Thoracic Particulate Mass TLVs (TPM-TLVs)* for those materials which are hazardous when deposited anywhere within the lung airways and the gas-exchange region.
c. *Respirable Particulate Mass TLVs (RPM-TLVs)* for those materials which are hazardous when deposited in the gas-exchange region.

The three particulate mass fractions described above are defined in quantitative terms as follows:

a. Inspirable Particulate Mass consists of those particles that are captured according to the following collection efficiency regardless of sampler orientation with respect to wind direction:

$$E = 50(1 + \exp[-0.06\, d_a]) \pm 10,$$
$$\text{for } 0 < d_a \leq E\ 100\ \mu m$$

Collection characteristics for $d_a > 100\ \mu m$ are presently unknown. E is collection efficiency in percent and d_a is aerodynamic diameter in μm.

b. Thoracic Particulate Mass consists of those particles that penetrate a separator whose size collection efficiency is described by a cumulative lognormal function with a median aerodynamic diameter of 10 μm $\pm 1.0\ \mu m$ and with a geometric standard deviation of 1.5 (± 0.1).
c. Respirable Particulate Mass consists of those particles that penetrate a separator whose size collection efficiency is described by a cumulative lognormal function with a median aerodynamic diameter of 3.5 μm $\pm 0.3\ \mu m$ and with a geometric standard deviation of 1.5 (± 0.1). This incorporates and clarifies the previous ACGIH Respirable Dust Sampling Criteria.

These definitions provide a range of acceptable performance for each type of size-selective sampler. Further information is available on the background and performance criteria for these particle size-selective sampling recommendations.[1]

References

1. ACGIH: *Particle Size-Selective Sampling in the Workplace*, 80 pp. Cincinnati, Ohio (1984).

Chemical Substances and Other Issues Under Study

Information, data especially, and comments are solicited to assist the Committee in its deliberations and in the possible development of draft documents. Draft documentations are used by the Committee to decide what action, if any, to recommend on a given question.

Chemical Substances

Acetaldehyde
Acetomethylchloride
Acetophenone
Acrylic acid
Adipic acid
Adiponitrile
Bentonite
Benzyl acetate
Borax and boron compounds
Bromine pentafluoride
Bromochloromethane
Bromodichloromethane
Bromoform
n-Butyl acetate
2-t-Butylazo-2-hydroxy-5-methylhexane
Cadmium
Carbon disulfide
Carbon monoxide
Chromium
Chrysene
Dibutyl phenyl phosphate
Dichlorodiphenyl sulfone
Dichlorocyclopentadiene
2,4-D (2,4-Dichlorophenoxy acetic acid)
1,3-Dichloropropene
Dichlorvos
Diethylamine
Dimethylamino
Dimethyl acetamide
Dimethyl formamide
Dimethyl disulfide
Dinitrotoluene
Epichlorohydrin
EPN
Ethyl bromide
2-Ethyl hexanoic acid
Gallium arsenide
Gasoline (unleaded)
Glutaraldehyde
Glycol ethers
Graphite fibers
Heptachlor
Hexachlorobenzene
Hexachlorocyclopentadiene
Hexamethylene diamine
Jet, petroleum and diesel fuel
Inorganic lead
Malathion
Man-made mineral fibers
2-Methoxyethanol
Methyl bromide
Methylene diamine
4,4'-Methylene dianiline
Methyl tert-butyl ether
Mineral spirits
Naled
Nitromethane
Pentachlorophenol
2,4-Pentanedione
Perchloroethylene
Perfluoroisobutylene
Persulfates
Petroleum solvents
Propylene dichloride
Sulfur tetrafluoride
Sulfuryl fluoride
Tantalum
Terphenyls
Terephthalic acid
1,1,1,2-Tetrachloro-2,2-difluoroethane
1,1,2,2-Tetrachloro-1,2-difluoroethane
1,1,2,2-Tetrachloroethane
Tetrakis phosphonium chloride
Tetrakis phosphonium sulfate
Tetrasodium pyrophosphate
Tobacco smoke
Trichloroethylene
Triethanolamine
Triethylamine
Vinyl cyclohexene
Uranium

Other Issues

1. Solubility.
2. Should the TLVs currently expressed as "total dust" be changed to "inspirable particulate mass," as defined in Appendix D, without changing the numerical value?
3. Two working groups have been formed to address questions of:
   a. Altered work shifts.
   b. Skin notation criteria.
4. Excursion limits